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MINING ORE IN OPEN STOPES
CENTRAL AND EASTERN UNITED STATES

BY

CHAS. F. JACKSON

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MINING ORE IN OPEN-STOPES CENTRAL AND EASTERN UNITED STATES[1]

By Chas. F. Jackson[2]

INTRODUCTION

This paper is published as a progress report for the first half of 1929 on the study of mining methods and costs in the Eastern and Central States. Data obtained from 20 mines using open-stope methods are correlated and summarized. Some of these mines have been described in considerable detail in reports already published as Information Circulars. In addition to the published reports on individual mines, considerable data have been obtained from other mines which were visited and studied during the course of the investigation. Many of these mines will later be described in detail in separate papers, and when the field has been covered in this manner it is planned to issue a bulletin on open-stope methods of mining which will amplify the subject matter of the present paper.

Definition of "Open-Stope".- The term "open-stopes" as employed by the Bureau of Mines is applied to all naturally supported stopes; that is, stopes in which the excavated ore is not replaced by support of an artificial nature other than props or stulls and in which the ore or (and) capping are not caved during the active life of the stopes.

Such stopes may have no other support than that afforded by the margin walls and the arch of rock over the back, or pillars left within the stope as additional support to the back. Thus we have:

(1) Simple open-stopes without pillars (usually confined to thin ore bodies having strong walls (figs. 1 and 9).

(2) Open-stopes with pillar support (figs. 2-3-4).

In open-stopes with pillar support, the pillars may be of the casual or irregular type (fig. 2) or may be spaced at regular intervals between the stopes (figs. 3 and 4). The former are often roughly circular in plan but may be very irregular in shape. The latter are usually rectangular and with the stopes constitute a somewhat regular geometrical pattern.

Some shrinkage stopes are in reality open-stopes, as when the broken ore is left merely to provide a working floor close to the back upon which the miners stand in attacking

1 - The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from U. S. Bureau of Mines Information Circular 6193.

2 - Mining engineer, U. S Bureau of Mines.

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the solid ore overhead. In other cases, however, the broken ore serves to some extent as a support to the hanging wall; in the bureau classification of mining methods, shrinkage stopes are placed with "filled stopes" or "stopes artificially supported."

Production - Incomplete statistics, which, however, include the production figures of most of the larger mines in the Eastern and Central States, show an annual production of ore in excess of thirty-one million tons from open-stopes as defined above, indicating the importance of such methods.

LIMITATIONS AND VARIATIONS OF METHOD

Broadly speaking, the open-stope method is confined to the mining of strong to moderately strong ore bounded by strong to moderately strong walls. Considerable latitude is allowable in this respect, however, depending upon the size, shape, and dip of ore body; depth of cover; nature and position of the slips and joints in ore and walls; and upon the grade and uniformity of mineralization of the deposit.

Thin, Tabular Deposits.- A thin, tabular body of weak ore lying between firm walls may be mined successfully by underhand stoping beneath an arched or stull-supported back or by sublevel stoping (fig. 9), while if the walls were only moderately strong this method could still be employed by using stull timbers from wall to wall spaced at intervals throughout the stope. Still weaker walls would require that the cut and fill method be employed. With very weak and friable ore, relatively low in grade and having weak walls, it would probably be preferable to use the caving method; if the ore were high grade, top-slicing or square setting might be employed. As the border line is approached between conditions permitting the use of open-stope methods and those requiring other methods, the selection of the proper system of mining becomes more difficult and requires careful consideration of all the factors involved.

Some thin, flat ore bodies with moderately strong roof are mined in open-stopes by methods similar to those employed in coal mines (fig. 4). At Birmingham, Ala., beds of soft iron ore dipping at a flat angle, up to 20 feet thick and averaging 8 to 10 feet in workable thickness, lie beneath a roof composed of slate and sandstone beds. The existence of water-saturated strata at some distance above the ore beds makes it imperative to support the roof. This is accomplished by employing a room-and-pillar system in which about 30 per cent of the ore is left in pillars and which is very similar to that used in bituminous coal mines. In some of these iron-ore mines the rooms are driven 50 feet wide on 75-foot centers and about 150 feet long. In another mine, rooms are 100 to 175 feet wide with three room necks connecting the room to the entry. In the latter case small casual pillars, locally termed "captain's pillars" are left as required between the regular room pillars to support the back. Props are also used as temporary local support to bad patches of roof.

Where conditions do not require permanent support of the roof it is suggested that a longwall system of mining might be employed in which the roof would be temporarily supported by props close to the working face and as mining progressed would be caved by removing or blasting the props. The writer has no record of the employment of such a method in ore mines of the Eastern and Central States, however.

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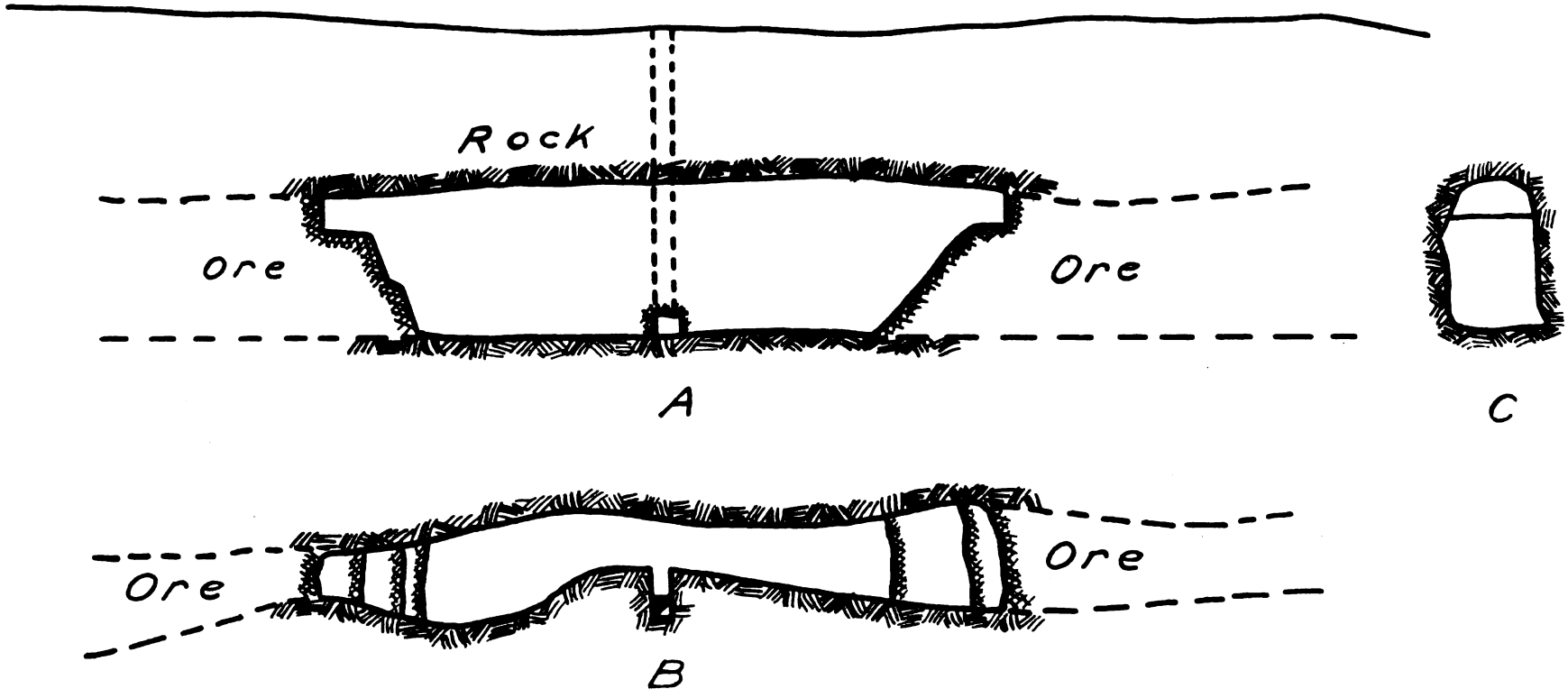

Figure 1. Simplest Form of Open Stope without pillars.
A, longitudinal section; B, plan; C, transverse section.

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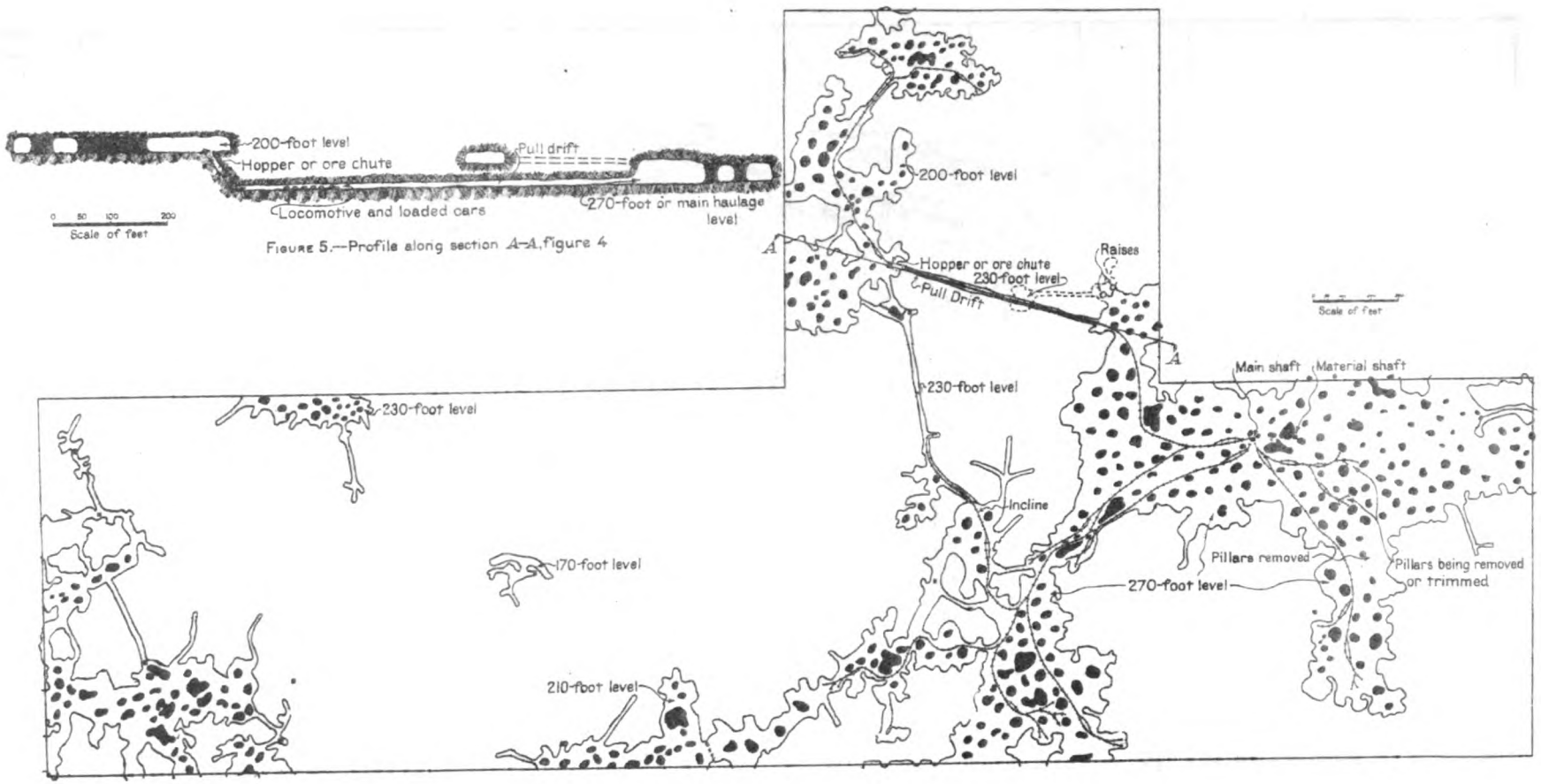

Figure 5.—Profile along section A–A, figure 4

Figure 2. Open Stopes with Irregular Pillars.

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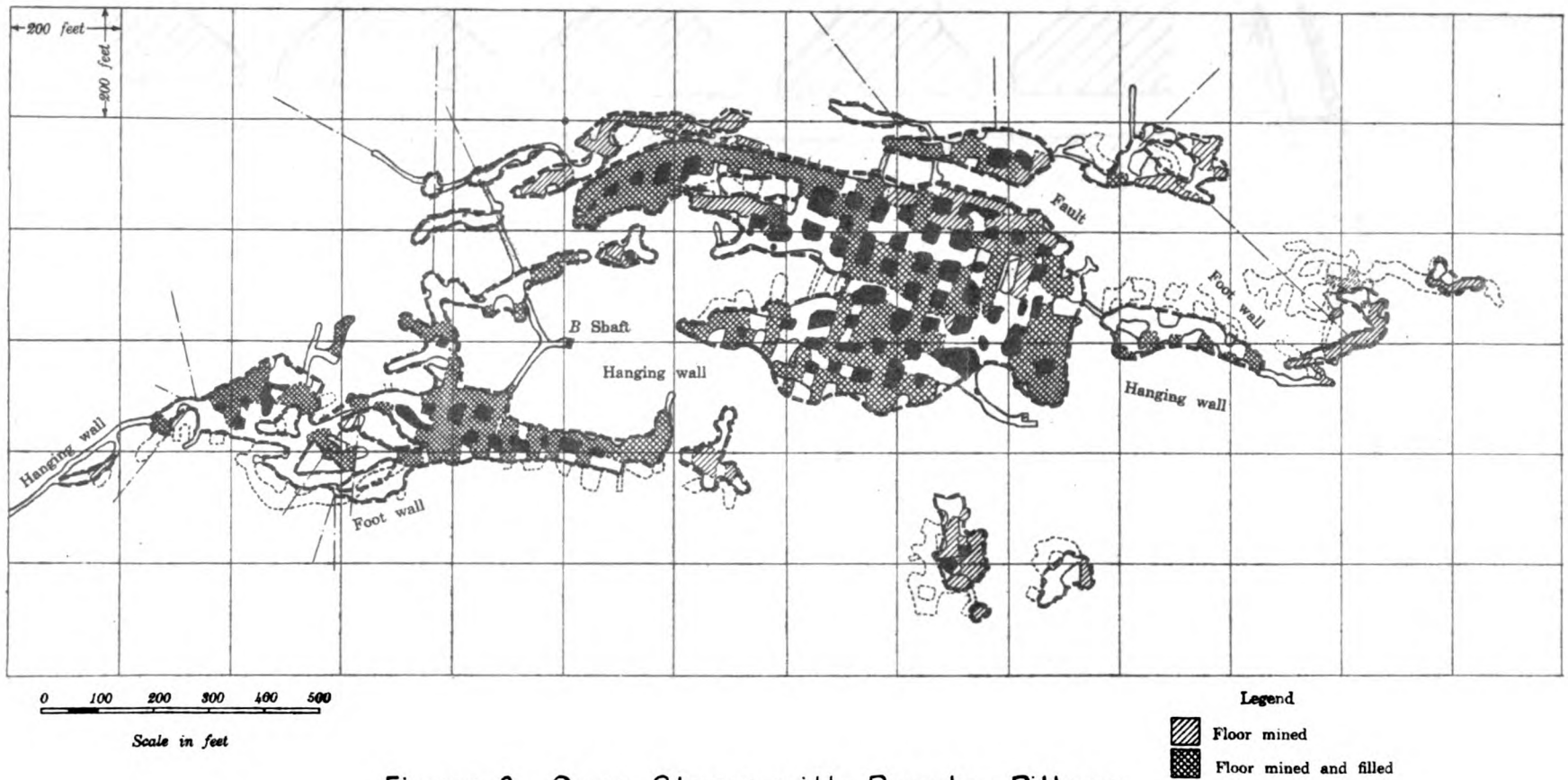

Figure 3. Open Stopes with Regular Pillars.

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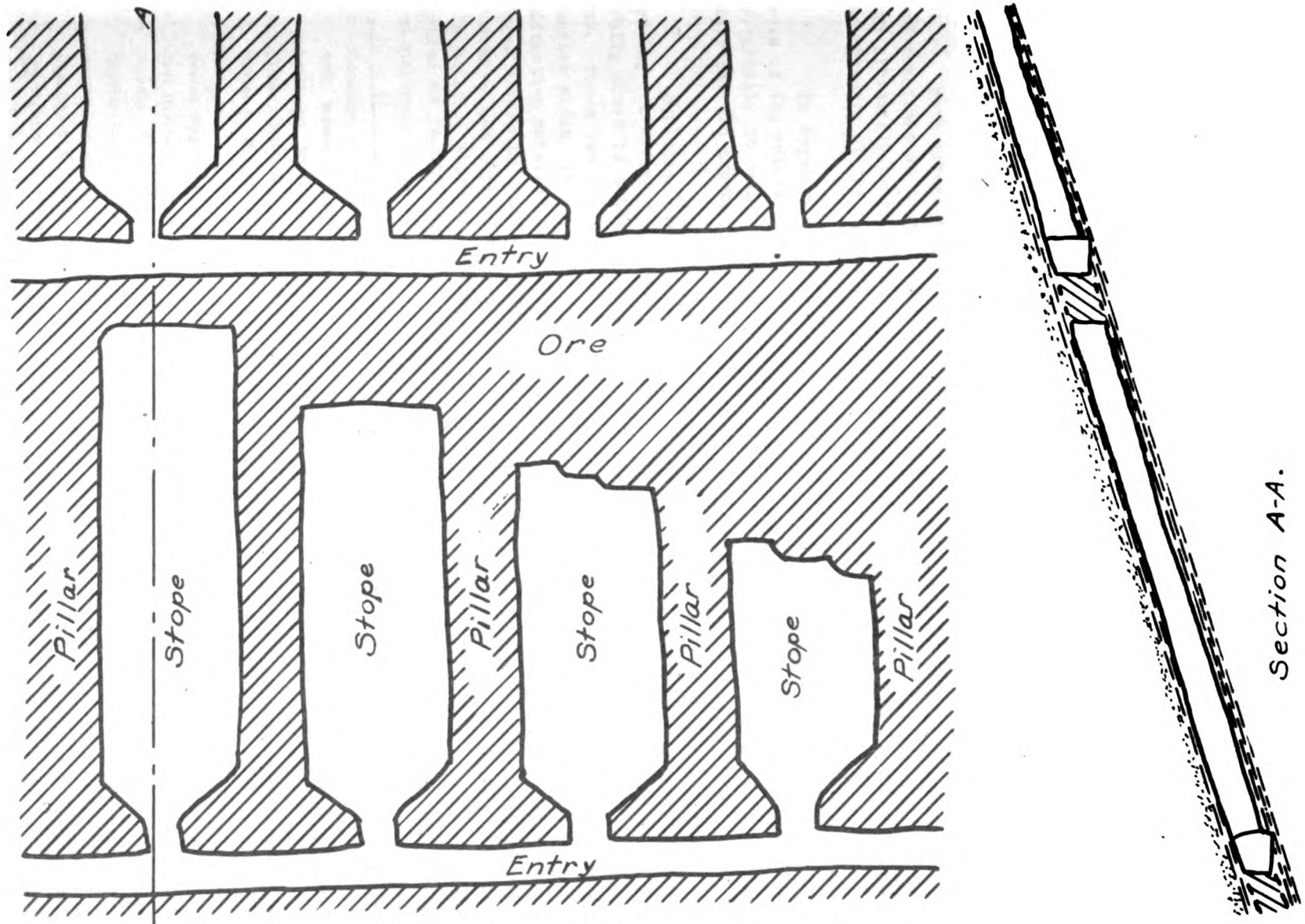

Figure 4. Open Stopes with Regular Pillars.

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Where open-stopes with casual or irregular pillars are employed it is sometimes possible to confine pillars to low-grade or barren rock. In this case their ultimate recovery is of small importance. In other cases where pillars are in good ore, their recovery becomes a matter of considerable moment.

Recovery of Pillars.- With a regular stope and pillar arrangement it is impossible to confine the pillars to low-grade or barren rock, and if the ore is high grade, it may preclude the use of this method entirely or make it necessary to fill the stopes and then mine the pillars by some other method.

With irregular pillar arrangement, 10 to 25 per cent of the volume of the ore body, and sometimes as much as 40 per cent, is left in pillars.[3] In many cases most of this ore can ultimately be recovered by robbing operations, starting at the margins of the ore body or boundary of the property and retreating therefrom.

In regular room and pillar work, the pillars may constitute 35 to 40 per cent or more of the entire volume of the ore body.[4] Under such conditions it is obviously necessary eventually to adopt some method for the recovery of pillar ore if the value of the ore warrants the expense of recovery.

Sublevel Stoping.- Some moderately wide or wide bodies of moderately strong to strong ore having moderately strong to strong walls and dipping at steep angles are successfully mined by sublevel stoping, a variation of the open-stope method (figs. 5,6,7,8, and 9). Where the ore body is long and not too wide for spans to be self-supporting over the entire width, it is stoped out full width, and the sublevel stoping faces are advanced in a direction parallel with the long dimension of the ore body (fig. 5B). Wider ore bodies are also worked by sublevel stoping, but the ore body is divided into several transverse sublevel stopes separated by intervening pillars[5] (fig. 5A). At the Porcupine Paymaster[6] mine in Ontario, where the ore body was about 110 feet in width, transverse sublevel stopes were mined 60 to 100 feet long with intervening 30-foot pillars. The dip was about 60°, and stopes were up to 200 feet high. Experience with the first stopes indicated that they could

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3 - Cummings, A. M., Method and Cost of Mining Magnetite in the Mineville District, New York. Information Circular 6092, Bureau of Mines, 1928, p. 7.
Netzeband, Wm. F., Method and Cost of Mining Zinc and Lead at No. 1 Mine, Tri-State Zinc and Lead District, Picher, Oklahoma. Information Circular 6113, Bureau of Mines, 1929, p. 9.
Banks, L. M., Mining Methods and Costs in the Waco District. Information Circular 6150, Bureau of Mines, 1929, p. 6.
Poston, Roy H., Method and Cost of Mining at No. 8 Mine, St. Louis Smelting and Refining Company, Southeast Missouri District. Information Circular 6160, 1929, 23 pp.
Jackson, C. F., Method and Cost of Mining Disseminated Lead Ore at a Mine in the Southeast Missouri District. Information Circular 6170, Bureau of Mines. - In press.

4 - Eaton, Lucien, Method and Cost of Mining Hard Specular Hematite on the Marquette Range, Michigan. Information Circular 6138, Bureau of Mines, 1929, p. 11.

5 - McNaughton, C. H., Mining Methods of the Tennessee Copper Company, Ducktown, Tennessee. Information Circular 6149, Bureau of Mines, 1929, 17 pp.

6 - Hubbell, A. H., Low-Grade Ore in Ontario. Eng. and Min. Jour., Nov. 10, 1928, p. 741; Nov. 17, 1928, p. 785.

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safely be carried 100 feet in length, and some of the earlier pillars were later extracted, leaving open-stopes 120 feet by 110 feet by 175 feet high.

A set of conditions suitable for sublevel stoping methods may, in a given case, approach those requiring a different method of mining such as shrinkage, cut-and-fill, or, with much weaker or more friable ore and wall rocks, sublevel caving or even top-slicing. Only careful consideration of all the factors will determine the best method to use.

In sublevel stoping, the faces on each sublevel are usually carried in advance of those on the sublevel next above (figs. 5 and 6). Where the ore itself is very firm and strong and free from prominent slips and joints, each bench of ore may overhang the sub below by as much as 40 feet (fig. 5); the overhanging ore is then benched down from the top in several steps or stages. More often the stope is carried as in Figure 6. In weaker ore, each sublevel overhangs the one below by only a few feet or the stope face is kept vertical (fig. 7). In still weaker ore the slope is slightly reversed (figs. 8 and 9). The vertical interval between sublevels is commonly 20 to 40 feet.

Where the sublevel method is used the men drilling the side cuts and benches are always working under the protection of solid ore; any rock dislodged from the levels above falls out in the stope well away from the miners below. Where there are large inclusions of barren material in the ore body it is possible to leave such material as pillars in sublevel stoping.[7] Smaller inclusions of waste can be kept separate from the ore by drawing the stope empty, blasting down the waste, drawing this out, and then resuming breaking of the ore.

It is suggested that the sublevel method might be employed advantageously in some mines now using shrinkage stoping and particularly in sulphide ores which it is advisable to remove from the stopes as soon as broken. The physical conditions to which sublevel stoping are applicable are practically the same as those for shrinkage stoping, and can be employed in ground too soft for shrinkage stoping. A sublevel stope is in effect a shrinkage stope turned on end, in which the ore can be drawn off as fast as broken. Sublevel stopes can be employed in wider ore bodies and under a wider range of conditions than shrinkage stopes. The dip of the ore body must usually be 50 to 55° or steeper, though at one mine visited the method was being successfully employed on a 45° dip.

At one mine where shrinkage stoping was abandoned and sublevel stoping was resorted to the following advantages were claimed:[8]

1. Sublevel stoping is safer due to the fact that the men are not out under a wide back but are always under solid ground which can be and is tested daily.

2. The total breaking cost is less in sublevel stoping than in shrinkage stoping, largely due to the fact that the ore is broken finer from the solid with less secondary breaking in the sublevel stopes. In the shrinkage stopes large slabs would come down which

7 - McNaughton, C. H., Work cited, p. 12.

8 - McNaughton, C. H., Work cited, p. 12.

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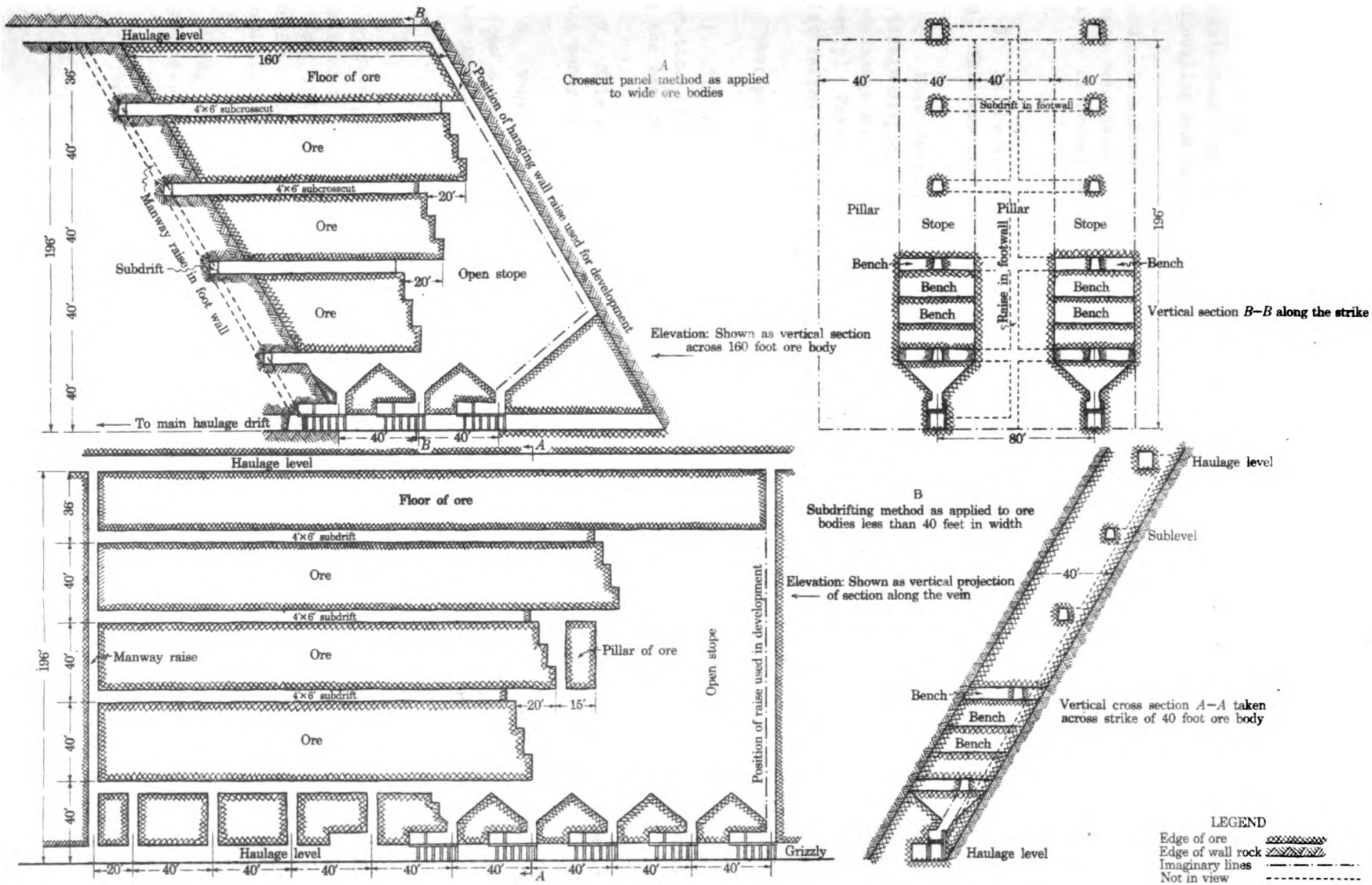

Figure 5.– Method of developing and mining sublevel stopes

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had to be drilled and blasted, and often fell in such a position in the stope that it was dangerous to go out under the stope to break them up.

3. The drawing of the ore from sublevel stopes can be concentrated at fewer pull-hole points than from shrinkage stopes to secure the same rate of output, thus securing increased pulling and haulage efficiency.

4. In sublevel stopes a greater percentage of the ore is recovered. In the shrinkage stopes considerable ore was often left on the footwall due to minor folding. This ore can only be recovered by open-stoping in which the footwall is exposed throughout the operation.

5. In the sublevel stopes very lean or barren portions of the ore body are left as pillars. This was usually very difficult to do in shrinkage stopes.

6. More development and stope preparation are required for sublevel stoping than for shrinkage stoping. The difference, however, is not as great as might first appear, because shrinkage stopes required closer spacing of pull holes in order to draw the shrink down evenly. Furthermore, with shrinkage stopes it was found advisable to carry footwall or pillar raises in addition to cribbed manways through the broken ore.

Other points not included in the foregoing are as follows:

1. The retention of broken ore in shrinkage stopes interferes in some cases with the flotation efficiency, due to surface oxidation of sulphide particles. In sublevel stoping the ore is, or may be, drawn off immediately after it is broken.

2. This ability to draw the broken ore at once results also in a saving due to the fact that money is not tied up for a long period in broken ore standing in stopes.

3. Where only one grade of ore is mined it is possible to obtain a high rate of output from a few sublevel stopes since mining can proceed simultaneously on a number of sublevels in each stope with the advantages attendant upon concentrated operations.

APPLICATIONS OF OPEN-STOPE METHODS OF MINING

Open-stopes, with and without pillars, are employed under a wide range of conditions. They are used in thin beds and veins lying at inclinations varying from the horizontal to the vertical and in deposits of 150 feet or more in thickness, both flat and standing at steep angles. Open-stopes are probably used more extensively and under a wider range of conditions than is generally realized.

Mining operations in the Central and Eastern States offer many examples of this method of mining and of its variations.

The copper and iron mines of Michigan, the zinc and copper mines of Tennessee, the

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magnetite mines of New York State, the Tri-State zinc and lead mines, the lead mines of Southeastern Missouri, and the iron mines of Alabama, all afford examples of this method of mining.

Michigan Copper District.- In the Michigan copper district three types of open-stopes are employed - namely, large, square, open-stopes with stull support; large open-stopes with large pillars; long, narrow stopes with long narrow rib pillars.[9] Here the workable lodes commonly vary in thickness from 4½ to 18 feet, though locally they are as much as 50 feet thick. Open-stopes are employed on the flatter dips of 30 to 40°, but where the dip is steep, cut-and-fill or shrinkage stoping are resorted to.

Michigan Iron Mines.- In the iron-ore mines of Michigan, open-stopes with pillar support are employed in hard ore[10] and sublevel stopes in somewhat softer ore. In other mines of this district top-slicing, sublevel caving, block-caving, and shrinkage stoping are employed. The district presents a wide range of conditions and in some cases it is difficult to determine which method of mining is most suitable. Factors such as support of stopes and surface, safety, cost of mining, rate of output desired, development required, percentage of extraction, and dilution of ore by admixture of low-grade inclusions or wall rock must all be taken into consideration.

At the Carpenter Mine in Michigan, a novel variation of sublevel stoping was employed in mining an iron-ore deposit overlaid by sand and gravel 175 feet in depth containing considerable water.[11] The ore body was divided into alternate sublevel stopes and pillars, and the stopes on each side of a pillar were filled by caving the surface before extraction of the pillar was begun.

In the harder iron ores, sublevel stopes are usually mined with each sublevel lagging behind the one next below (fig. 6). It is usual to try to keep the overhang between subs 8 feet or less. Benches are carried along the stope face by drilling and blasting slabbing cuts. Down and up holes are drilled from and in these benches, and the ore is broken into mills below. Stopes vary in width up to 150 feet, and in length up to 200 feet or more. Usually before the larger dimensions are reached the roof will cave. In this event it is usual to leave a thin pillar against the cave and resume the stoping behind this pillar. The majority of the caves will have been beneficial rather than otherwise, as the weight will be taken from the unmined ore and backs of the openings therein.

In somewhat softer ore the face of the stope is kept vertical - that is, without one sub appreciably overhanging the other. Figure 7 illustrates one method employed under these conditions; no bench was carried and the face was blasted off with holes pointed

9 - Crane, W. R., Mining Methods and Practice in Michigan Copper Mines. Bull 306, Bureau of Mines, 1929.

10 - Eaton, Lucien, Work cited

11 - Wortley, R. B., Novel Method of Sublevel Stoping. Eng. and Min. Jour., vol. 126, No. 22, 1928, p. 867.

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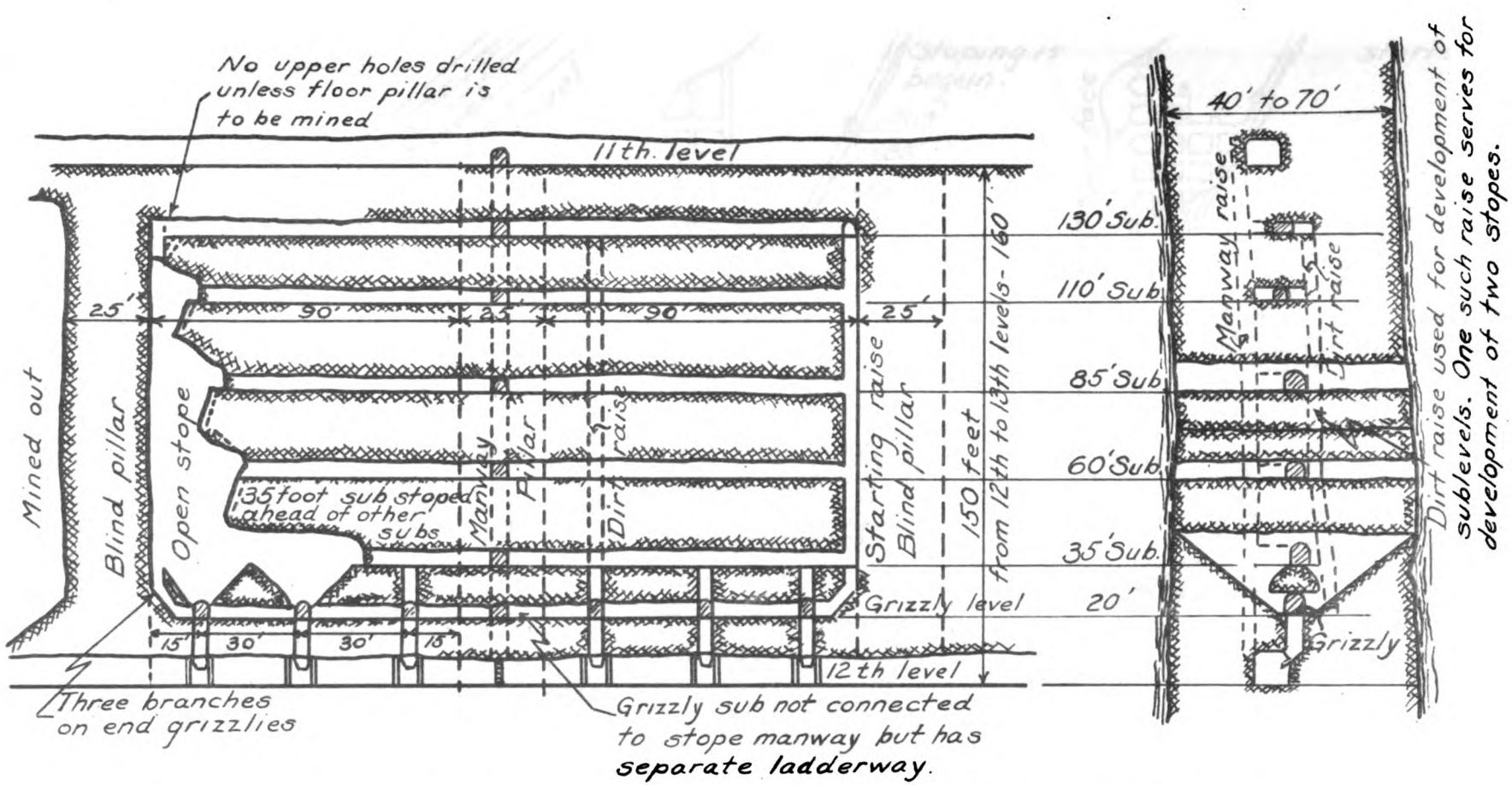

Figure 6. Sublevel stoping in moderately firm and hard ore; stope face overhanging.

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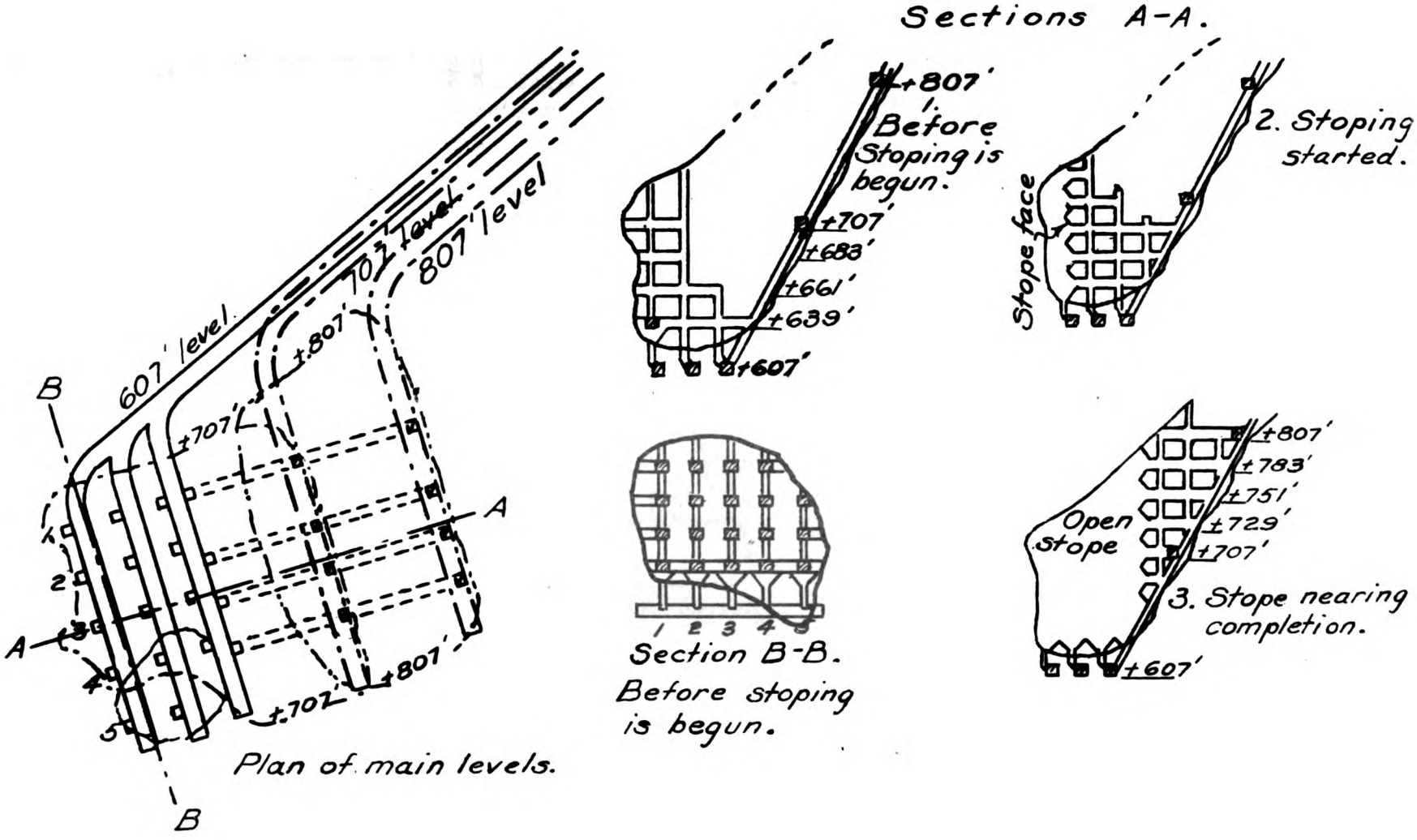

Figure 7. Sublevel stoping in comparatively weak ore; stope face kept vertical.

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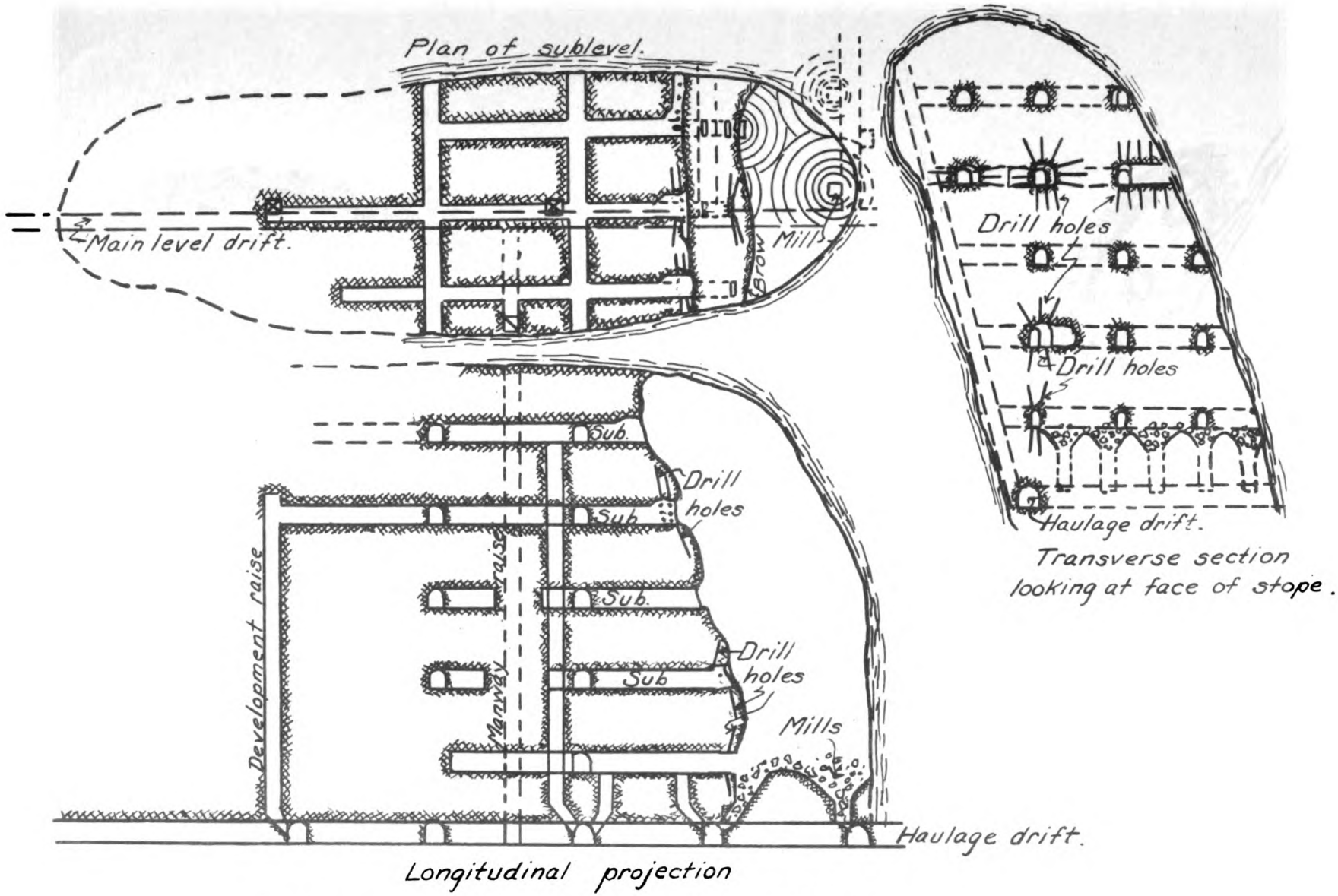

Figure 8. Sublevel stoping in weak, soft ore, Stope faces sloping outward.

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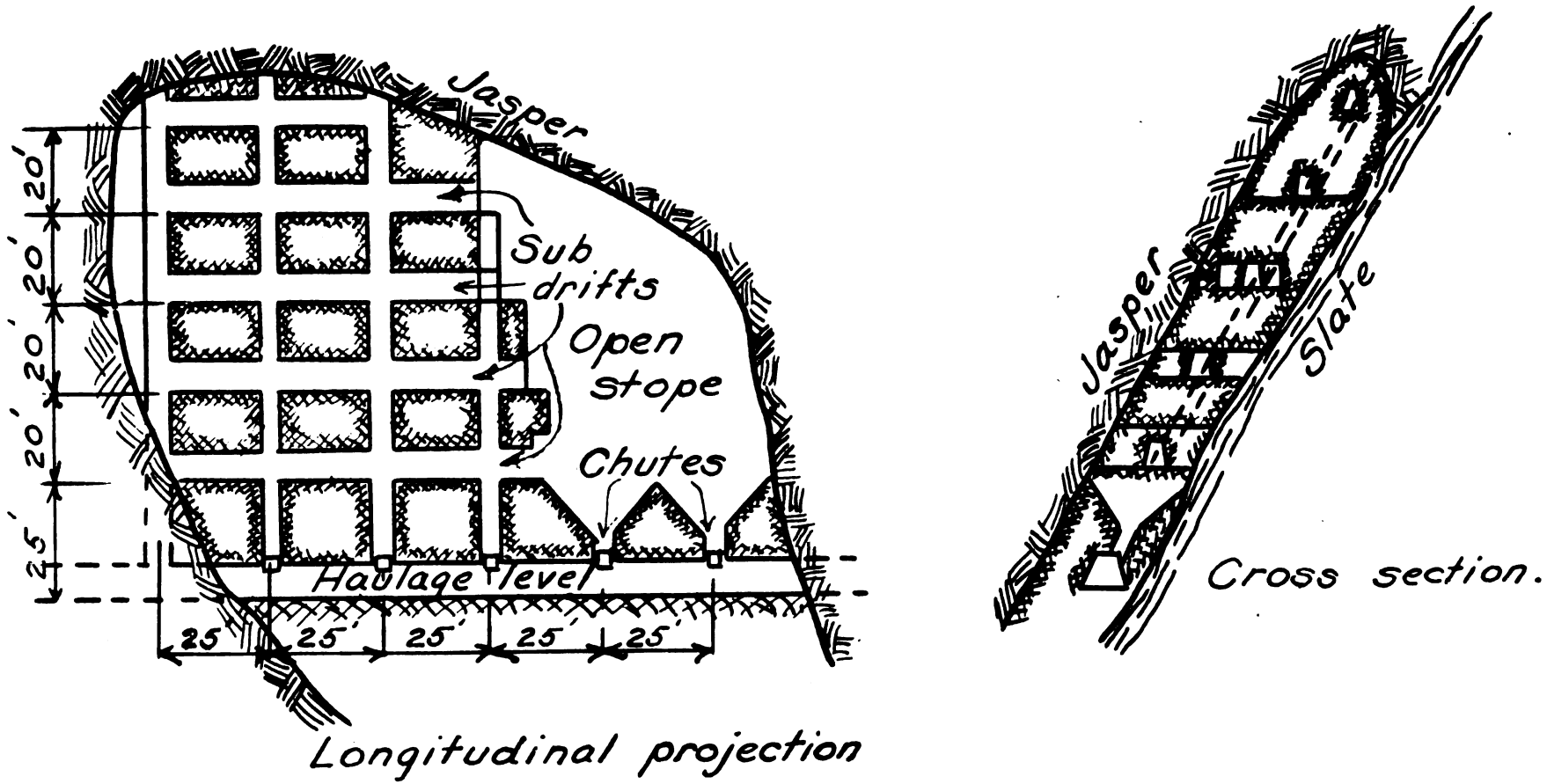

Figure 9. Sublevel stoping in narrow body of soft ore.

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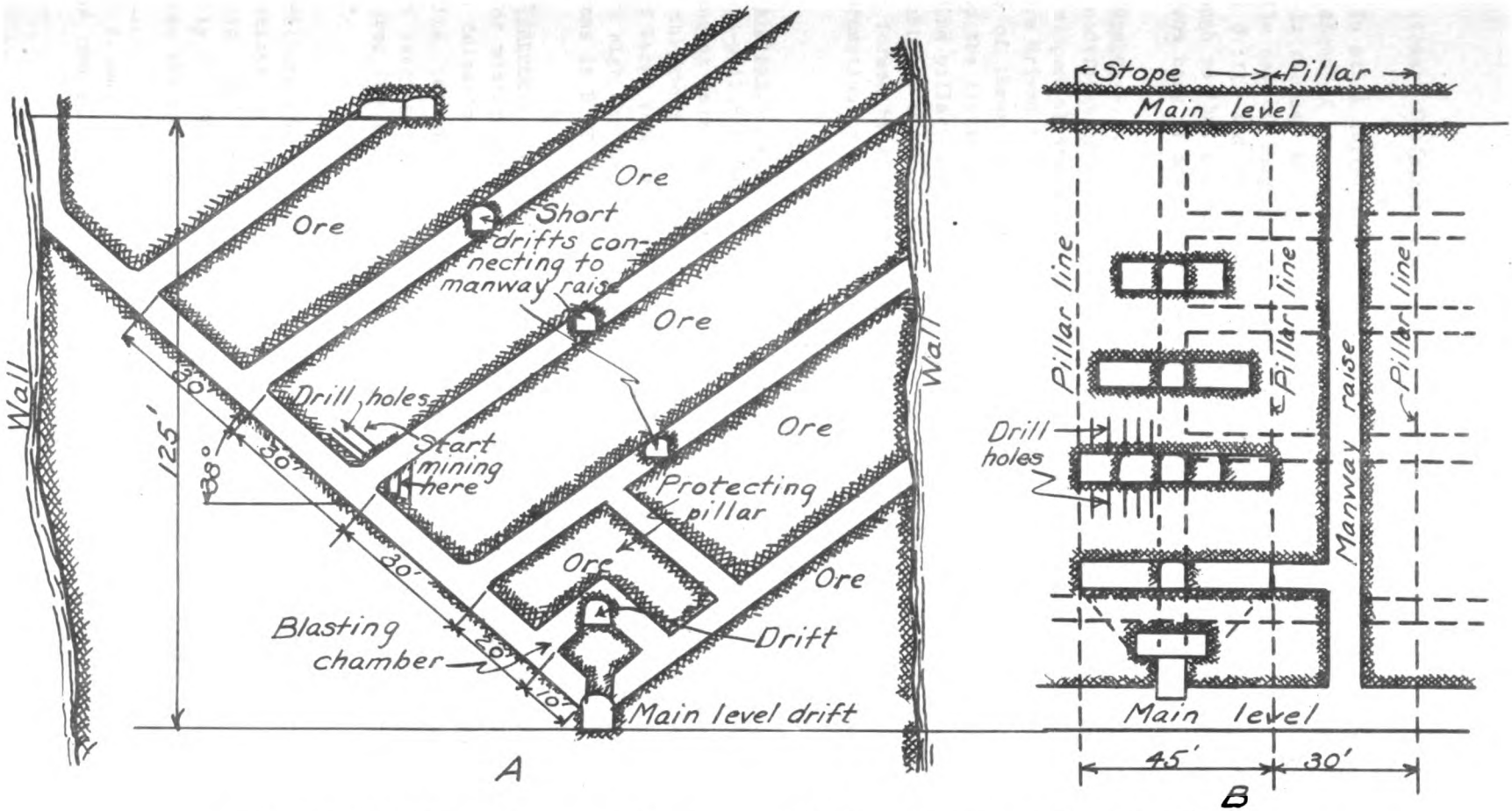

Figure 10. Development for open stoping from inclined raises. Raises widened to stope boundaries and floors between are broken out.

A, Longitudinal projection; B, Transverse section.

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forward (toward the stope) and drilled from the subdrifts.

In still softer and weaker ore which will not support benches at all each sublevel is kept ahead of the one below, as shown in Figure 8. Here the subdrifts are driven very small. In mining, the drift is enlarged by slabbing cuts just back of the stope face to permit the use of long steel; holes are drilled upward, downward, and laterally from the enlarged drift, and are blasted together. In one mine employing this method, the ore is soft enough so that all drilling is done with auger steel. Figure 9 shows a sublevel stope in a narrow body of soft ore having strong walls.

Quebec.- At the Noranda mine in Quebec, some of the ore bodies are being mined by another modification of the open-stope method (fig. 10). The ore body is blocked out into 40-foot stopes alternating with 30-foot pillars, levels being 125 feet apart vertically. Raises are driven from both sides of the drift at an inclination of 38° from the horizontal. From one of these raises branch raises are driven at 30-foot intervals on an inclination of 38° to the limits of the ore. These are breasted out to the width of the stope, and the intervening pillars are benched out as in sublevel stoping. This method may be considered to be sublevel stoping in which the subs are inclined instead of horizontal. Blasting chambers formed by short incline raises meeting above the haulage drift and connected at the intersection by a drift directly over the level are provided for blasting large chunks or ore.

Alabama.- In the Birmingham district bedded deposits of red iron ore are mined by a room-and-pillar system similar to that used in bituminous coal mines (fig. 4). The beds dip at angles less than that of the angle of repose for the broken ore and average 8 to 10 feet in thickness. The overlying strata must be supported by pillars to prevent the entrance of large volumes of water. In some of these mines scraper loading has been developed to a very high degree of efficiency. The mining practice in this district is described by W. R. Crane in U. S. Bureau of Mines Bulletin 239.

Tennessee.- At Mascot, Tenn.,[12] large open-stopes with irregular pillars are employed for mining large bodies of low-grade zinc ore. These ore bodies occupy fractured zones in dolomite in which the fractures have been healed or recemented by zinc sulphide and calcite, tending to form a very strong, firm structure. The ore bodies are of variable thickness ranging from a few feet to 150 feet. Very abrupt changes in thickness from 20 feet to over 100 feet are common. The average dip of the ore and enclosing formations is about 18°.

Pillars are roughly circular and extend from the bottom to the top of the ore horizon. Sometimes it is possible to locate the pillars in the leaner ore, but often this can not be done. The roof stands well between the pillars, and since mining starts at the top, opportunity is afforded to dress down the back thoroughly before underhand stoping operations place the back beyond reach of inspection and care.

12 - Coy, H. A. and Noble, James A., Mining Methods at Mascot Mines, Tennessee. Trans. Am. Inst. Min. and Met. Eng., vol. 72, 1925, pp. 54-76.

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Some mines in the Ducktown district in Tennessee employ sublevel stopes in large bodies of low-grade cupriferous pyrites. At one mine[13] the ore body attains a maximum thickness or width of 180 feet; the average dip is 65° but varies from 70 down to 35°.

In the narrower sections of the ore body, averaging 40 feet in width, longitudinal sublevel stopes are taken out from wall to wall (fig. 5B). In the wider section transverse stopes are carried 40 feet in width alternating with solid pillars of ore 40 feet thick (fig. 5A). The walls are highly metamorphosed sedimentary schists and graywacke with the schistosity roughly paralleling the ore body in strike and dip. Ore and walls are generally self-supporting over spans up to 100 feet in width except where weakened because of sharp folding of the strata.

At other mines in the Ducktown district a room and pillar system is employed wherein wide bodies of ore 200 feet or more in height are mined by underhand stoping. The ore body is blocked out by a checkerboard system, or rooms approximately 70 feet square with intervening 30-foot pillars. These blocks are each developed by a vertical raise from the haulage level to the top of the ore or to the next level above, and the ore is stoped out by benching around the raise, starting at the top. Where the ore extends over more than one level, floor pillars are left under the levels. This system is the old Cornish "underhanding" system of mining.

Anyox, British Columbia.- At the Hidden Creek mine, Anyox, British Columbia, a modification of open-stoping is employed in which spiral benches are cut around a central well or open-stope from which the ore is blasted in a manner similar to that employed in sublevel stopes.[14]

New York State.- At the magnetite mines in New York State[15] open-stopes supported by irregular pillars of ore are employed for mining a bedded deposit averaging 10 feet of workable ore, the thickness varying, however, from 3 to 40 feet. The ore beds are interstratified with gneissoid rocks and in places the ore grades off into the country rock. Twenty-five per cent of the ore is left in pillars, most of which will ultimately be recovered.

Tri-State District.- In the Tri-State zinc district the common method of mining employed is that of open-stopes with irregular pillar support.[16] In rare instances timber support and even spiling are required. In the narrower ore bodies or runs, it is often possible to mine the full width of the ore with headings or breasts driven at the top,

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13 - McNaughton, C. H., Work cited.

14 - Lindsay, W. R , and Healy, R. L., Mining Methods at Hidden Creek Mine, Anyox, British Columbia Canadian Min. Jour., Apr. 26, 1929, pp 383-385.

15 - Cummings, A. M., Work cited.

16 - Netzeband, Wm. F., Information Circular 6113 and 6121, cited
Banks, L. M., Work cited.
Keener, C. W., Work cited.

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following by underhand stoping of the bench (fig. 1). In this case the roof is self-supporting between walls, especially if it is well arched. The ore is flat-lying, though there are local dips and runs in the floor of the main ore bodies. These are mined from slopes or winzes. The ore ranges in thickness from a few feet to 100 feet or more. The size and spacing of pillars depends upon the height of ore as well as upon the local roof conditions.

In the wider ore bodies 12 to 25 per cent of the total ore is left in pillars, much of which can often be recovered during the final stages of mining. The amount of pillar ore that can be recovered will depend largely upon the nature of the immediate capping.

Southeast Missouri.- In the Southeastern Missouri lead district open-stopes with irregular pillar support is the usual mining method.[17] Here galena occurs disseminated through dolomite and shaly beds in horizontal sheets along bedding planes, in vugs and cavities, filling and lining the walls of joints, and as aggregates of cubes in open channels. These occurrences are found at several horizons principally in the Bonne Terre dolomitic limestone which has a normal thickness of about 375 feet. Sometimes these horizons are connected by bodies of ore cutting across the bedding, and stopes attain heights up to 200 feet and are supported by marginal walls and by pillars.

The ore and roof usually stand well, since it is very strong and uniform. An unique feature of the practice in this district is the method of inspecting and dressing the roof.[18] Timber scaffolding is supported upon iron hangers inserted in holes drilled in the roof. Access to the scaffolding is secured from a point on the side of the stope. Working from the scaffold, the back is carefully tested and barred down, holes are drilled ahead of the suspended scaffold in which hanging rods are inserted, and the scaffold is then advanced another length of "set," after which the operation is repeated.

DEVELOPMENT

It has been shown that open-stopes are employed in mining ore bodies of various types, sizes, and dips representing a wide range of conditions. The development incident to preparing these ore bodies for mining naturally varies accordingly.

Tri-State District.- The simplest type of development is represented in the shallow mines of the Tri-State zinc and lead district, where a shaft is sunk to the bottom of a body of ore previously proved up by churn drilling. Wide headings are driven from the shaft, sometimes in several directions. The ore bodies are flat and the headings are breasted out 7 to 8 feet high against the back of the ore, and as they are advanced they are closely followed up by stoping of the bench to the bottom of the ore. These headings are carried the full width of the ore in narrow ore bodies or a width corresponding to the distance between pillars in wider ore bodies. The development is thus in reality a part of the stoping operation. However, corresponding to the level development in other metal mines,

17 - Poston, Roy E., Work cited.

18 - Jackson, C. F., Work cited.

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pull drifts (fig. 2) are frequently driven through barren rock from a shaft to an ore body or from one ore body to another. While ore is mined at more than one horizon in some mines of the Tri-State district, most of these mines may be considered as being one-level mines. Raises and winzes are therefore seldom necessary, though the former are sometimes driven to reach a body of ore above the main ore horizon and the latter to mine local runs, channels, or basins of ore below the main level. For the latter purpose flat slopes are frequently driven in ore also.

Further details of development in this district may be found in the following Information Circulars issued by the U S. Bureau of Mines:

Information Circular 6113, by Wm. F. Netzeband;
Information Circular 6121, by Wm. F. Netzeband;
Information Circular 6150, by L. M. Banks;
Information Circular 6159, by O. W. Keener.

Shafts are usually about 5 by 7 feet in cross section, and except for being cribbed through shale and badly broken ground are for the most part untimbered (fig. 11). These shafts are usually sunk on contract, the contract price ranging from $9 to $12 per foot in shale and $13 to $15 in rock.[19] The contractor usually furnishes only the labor and explosives, however; the mining company furnishes all equipment, materials, supplies, and power. Thus a shaft contracted at $13 per foot for sinking labor would cost the company about $20 per foot.[20] At some mines larger shafts are sunk and equipped for hoisting in cages or skips.[21]

Pull drifts are usually 8 by 8 feet and untimbered. Often they are driven on contract at prices ranging from $6 to $8 per foot for labor and explosives only, the total cost being $10 to $14 per foot including all labor explosives, power, insurance, compressed air, pipes, track steel, etc.[22]

Southeast Missouri.- In the Southeast Missouri lead district the ore bodies are usually larger than in the Tri-State, the production rate from single mines is much higher, and usually the mines are considerably deeper. The ore bodies are flat-lying as in the Tri-State district and range in thickness from a few feet to 200 feet or more. Here larger shafts are sunk and are equipped with self-dumping skips for hoisting ore in balance and

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19 - Netzeband. Wm. F. Information Circular 6113. cited. p. 4; Information Circular 6121 cited.
Banks. L. M. Work cited.

20 - Netzeband. Wm. F. Information Circular 6121. cited. pp. 3-4.

21 - Netzeband. Wm. F. Information Circular 6113. cited.
Keener. O. W., Work cited.

22 - Netzeband. Wm. F. Information Circular 6113 cited pp. 4-5; Information Circular 6121 cited. p. 5.
Banks. L. M. Work cited p. 9.
Keener. O. W. Work cited

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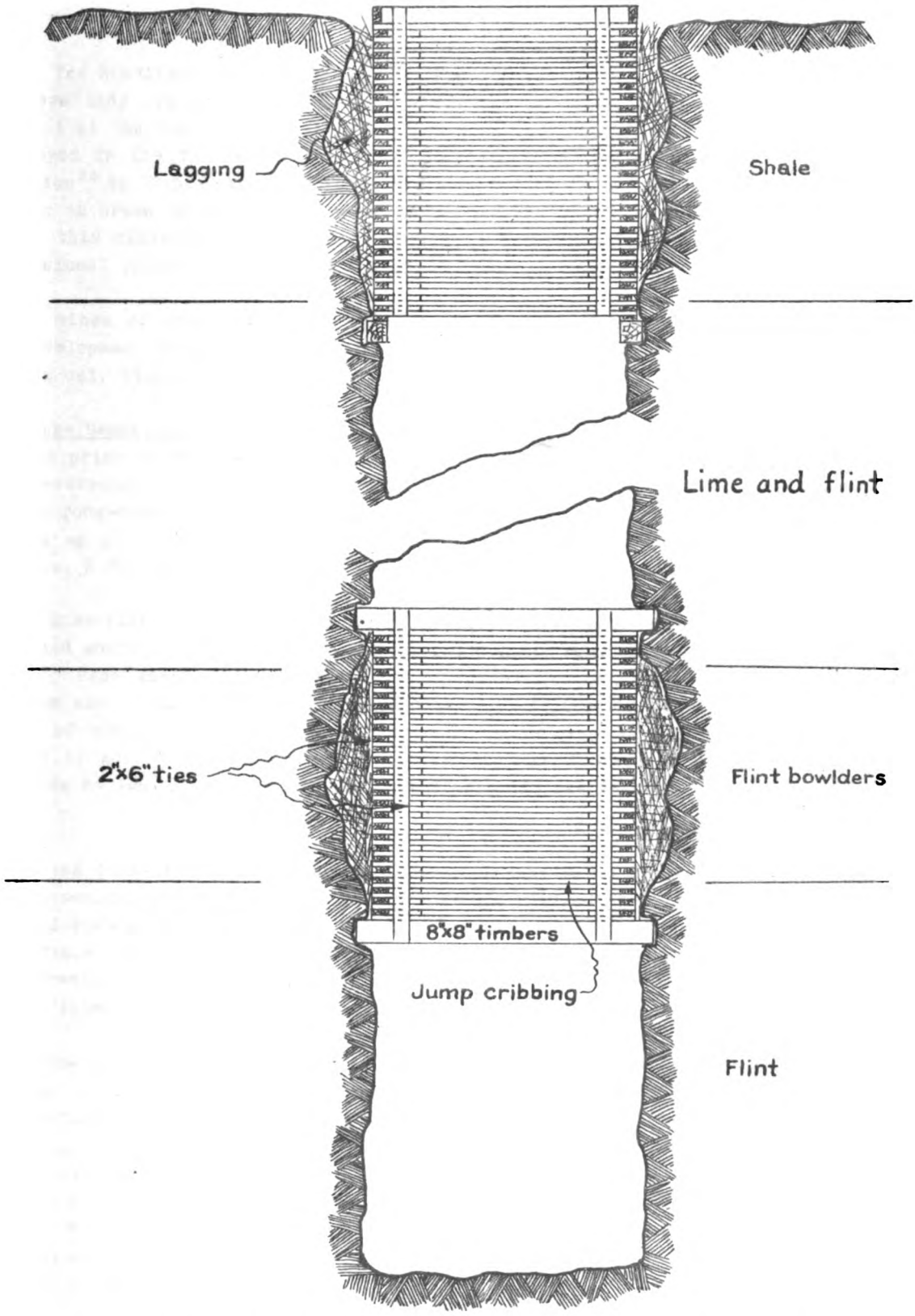

Figure 11. Section of shaft in Tri-State district showing method of support in heavy ground.

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with cages for handling men and supplies.[23] From these shafts drifts are driven to the ore bodies where they are opened out to the width between pillars to form stopes which are breasted out at the top of the ore and benched down in a manner similar in many respects to that employed in the Tri-State district. Development drifts are usually 7 by 8 feet in cross section[24] to 12 by 8 feet for larger haulage drifts.[25] At one mine 964 feet of drifts, 7 by 8 feet in cross section, were driven at an average cost of $7.87 per foot[26] in 1928.

In this district the ore often occurs at several horizons making it necessary to drive occasional raises, slopes, and winzes.[27]

In mines of the type represented in the Tri-State and Southeastern Missouri districts, development work is largely confined to that required to reach the ore. Once the ore body is cut, stoping is begun almost immediately.

Large Deposits on Low Dips.- In large deposits on low dips some development must be done in ore prior to mining in order to block out the ore body and prepare it for actual stoping operations. This may consist merely of driving the various haulage levels in ore and opening room-necks therefrom as at Birmingham, Ala. (fig. 4), or may involve in addition the putting up of raises as at Mascot, Tenn., and at the iron-ore mines in Michigan[28] and at Mineville, N.Y., where auxiliary shafts or slopes must also be driven.

At Mineville, N.Y.,[29] main haulage levels are driven in or on the footwall from the main inclined shaft at intervals of 1,000 to 1,500 feet, measured on the dip which averages 20 to 30°. From these levels crosscuts and raises are driven to the ore body in each faulted area and at intervals in unfaulted areas. The raises are driven to permit the installation of small ore pockets and the crosscuts to give easy access to the auxiliary shaft. One or more auxiliary shafts are driven in each faulted area both up and down the dip, starting at the top of ore pockets on the main haulage level.

At the iron-ore mines in Michigan vertical shafts are sunk to reach the ore horizons, and crosscuts are driven to cut the ore at the desired level intervals. These shafts are equipped with self-dumping skips and with cages for handling men, timber, and supplies. Level intervals are from 50 to 150 feet or more. The present tendency is to space main levels at greater intervals than formerly and to transfer ore through raises to the haulage levels from intermediate levels not connected with the shaft.

At one such mine where the ore is up to 40 feet thick and dips at an angle of 30 to 35° the ore is mined by a combination of open-stopes separated by regular pillars and shrinkage stoping. Crosscuts are driven to the ore body from vertical shafts at intervals

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23 - Poston, Roy H , Work cited Jackson, C F , Work cited

24 - Poston, Roy H., Work cited.

25 - Jackson, C. F., Work cited.

26 - Poston, Roy H., Work cited

27 - Jackson. C. F., Work cited.

28 - Eaton, Lucien, Work cited, p. 6.

29 - Cummings, A. N , Work cited, pp. 4,5,6.

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of 100 feet vertically, or about 150 feet measured on the dip. When the ore body is encountered, drifts are driven on or near the footwall, and from these drifts short mining raises are put up to the hanging wall on the center lines of the stopes to be mined later. From the footwall side of these short raises, inclined raises are then driven in ore and closely following the footwall through to the level above. Occasional raises are also run between levels within the pillar boundaries to serve as manways. This work is all preliminary to actual stoping operations.

At other iron mines[30] the ore body is blocked out by drifting and raising prior to stoping.

At Mascot, Tenn., levels are driven from the vertical shaft or from slopes tributary to the bottom level of the shaft just below or near the bottom of a thick ore body which dips at an average angle of 18°. Short inclined chutes are put up from the side of the level, and from these chutes vertical raises are put up to the hanging wall. Meanwhile small drifts or flat raises are driven through a pillar from the next level to serve as traveling roads. This work is all preliminary to actual stoping.

In the mines of the north range of the Michigan copper district where the present operations are at great depths, the working horizons are reached by vertical and inclined shafts. Crosscuts are driven at the various levels to cut the lodes, these levels being usually spaced about 100 feet apart. At present the common practice is to drift in or on the footwall parallel with the lode to the limits of the mining area and to begin mining at the ends and retreat toward the shaft. Raises are driven at intervals to connect the levels.

Large Ore Bodies on Steep Dips.- Large deposits of ore on steep dips worked by open-stope methods occur at Ducktown, Tenn., in the south range of the Michigan copper district, and in the iron districts of Michigan. They are usually reached by sinking vertical shafts, sometimes by inclined shafts. Crosscuts are then driven into the ore body at vertical intervals of 100 to 200 feet and from these crosscuts longitudinal drifts are run in ore, or drifts are driven parallel to the ore bodies in the footwall with crosscuts therefrom to the ore at regular intervals.

In these mines considerable stope preparation or development in ore is required to prepare for stoping operations. At Ducktown, Tenn.,[31] for example, the stope development in sub-level stopes amounts to 1 linear foot of combined raises and sublevels to 110 tons of recoverable ore developed.

Development Costs.- At 15 mines using open-stope methods in the Eastern and Central States which have been studied recently, development costs constituted on the average about 14 per cent of the total underground costs.

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30 - Eaton, Lucien, Work cited, p. 6.

31 McNaughton, C. H., Work cited, pp. 7-8.

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At mines in the Tri-State district current development is usually not carried as a separate item from stoping on the cost sheets, but it probably constitutes not more than 5 per cent of the total mining cost. At Mineville. N.Y.,[32] development represents 8.2 per cent of the total underground cost; in Southeastern Missouri it ranges from 5.1 to 18.7 per cent. At Ducktown, Tenn., the range is from 12 to 20 per cent. At the Burra Burra mine[33] in this district it was 20.2 per cent in 1928, but during that year the development was prosecuted much faster than was required to keep up with the rate of ore extraction. The normal cost of development at this property is probably around 12 to 15 per cent of the total underground cost. In open-stope mines of the Michigan copper district 16 to 25 per cent of the total underground cost is for development, and in the Michigan iron mines reported upon, the development cost was from 15.4 to 22.77 per cent of the total underground cost. The foregoing figures cover all development both in rock and in ore.

Some of the larger deposits having moderate to steep dips may be mined by any one of several different methods, depending upon the various details of physical conditions and economic considerations in different instances. Since in any event the preliminary main level development up to the encountering of the ore body is practically the same whether sublevel stopes, alternate pillar and stope, shrinkage stoping, cut-and-fill, slicing, or caving are to be used, it is of interest to determine the amount of stope preparation or stope development, as distinguished from total development, required prior to stoping in open-stope mines of this type. Practically all of this development is in ore. Since most of the mines of this type which have been studied in connection with the present investigation were using sublevel stoping, the following figures in Table 1 refer for the most part to mines using this method.

The figures given in Table 1, considered in the light of inspection and study of the mines, indicate quite conclusively that the amount of stope development required in any given case is a function of the strength of ore and wall rocks, particularly of the former; the stronger the ore, the less development per ton of recoverable ore will be required in mines using this method of stoping. This is perhaps more or less self-evident, but the figures taken from actual operations are interesting. Likewise the development per ton is naturally less in wide than in narrow ore bodies, other conditions remaining the same.

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32 - Cummings, A. M., Work cited. p 12

33 - McNaughton, C. H., Work cited, p. 17.

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Table 1.- Methods used to mine various types of ore deposits, showing relation of stope development to production.

Mine location	Nature of ore body	Nature of walls	Mining method	Tons of ore produced per lineal foot of stope development[1]	Feet of stope development per ton of ore[1]
Ducktown, Tenn.	Strong ore, cupriferous pyrite and pyrhotite, hard ore.	Firm.	Sub-level stoping. Stopes average 40 feet wide.	110	0.0091
Michigan	Iron ore. Firm and strong. Moderately hard.	Strong jasper and moderately strong slate.	Open-stope and pillar with shrinkage. Stopes 22 feet wide.	60	0.0167
Michigan	Iron ore. Firm and strong. Moderately hard.	Iron formation and pyritic slates. Moderately strong.	Sub-level stoping. Stopes average 50 feet wide.	45	0.0222
Michigan	Iron ore. Firm and strong. Moderately hard.	Iron formation and pyritic slates. Moderately strong.	Sublevel stoping. Stopes 25 to 60 feet wide	35	0.0303
Michigan	Iron ore. Firm, medium hardness.	Black slate. Moderately strong.	Sublevel. Stopes up to 100 feet wide.	55	0.0182
Michigan	Iron ore. Weak and fairly soft.	Iron formation and slate.	Sublevel stoping. Stopes 50 feet up to 100 feet wide.	20	0.0500
Ontario	Gold-bearing pyrites and quartz in hard, schisted albite porphyry.	Greenstone, hard and strong.	Sublevel stoping. Stopes up to 110 feet wide.	125	0.003
Quebec	Massive sulphides. Strong	Complex of schisted rhyolite andesite and diabase	Open-stopes benched from inclined raises	75	0.0133

1 - Figures are for stope preparation only, as distinguished from total development, and do not include main haulage levels

DRILLING, BLASTING, AND HANDLING

Ground of a character which lends itself to open-stope mining usually has a tendency to break large, particularly if planes of weakness are tight and spaced far apart. Following the breaking of the ore at the face, secondary breaking is often necessary either in the stope, on grizzlies, or in the chutes. On the other hand, the ground is often easy to

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drill, as in the zinc mines at Mascot, Tenn., the Southeast Missouri lead mines, and the iron mines of the Birmingham district. At Ducktown, Tenn., and at Ishpeming, Mich., the ore is harder.

In all these mines there is little trouble from "fitchering" and caving of the drill holes, as the joints, fractures, and bedding planes are relatively far apart. In the brecciated ore of the Tri-State district, however, the holes tend to cave, and this increases the difficulty in drilling. At Ishpeming, Mich., in hard specular hematite the drilling speed is retarded primarily by the hardness of the ore.

In practically all of the open-stope mines studied, regardless of the "drillability" of the ground, there is a tendency for the ore to break large, as above noted; therefore the problem of breaking always revolves around the proper placing and charging of the holes, whereas the actual drilling is a lesser problem, except at Ishpeming and in the Tri-State district.

At the Paymaster Mine in the Porcupine district of Ontario, where sublevel stoping was employed, the ore was in a schisted and silicified albite porphyry which was hard to drill and very abrasive - so much so that a drill was never good for more than one run (2 feet), and occasionally as many as 15 steels were required to drill 6 feet of hole. This ore broke large in the stopes in spite of the schistosity and slip planes, and much secondary breaking was required.

In the Tri-State district where the ore is mined by heading and benches, the drilling practice varies at different mines. The most common practice is to drill the stopes (or benches) with long flat holes, employing two man machines on tripods, even though the bedding is nearly horizontal. Vertical holes give more trouble from caving and fitchering, as the ground is badly brecciated. Recementing of the breccia fragments, however, serves to hold them together and permits the use of open-stopes. In this ground fast drilling machines are not a requisite, since the drilling speed depends more upon the amount of caving and fitchering than upon the weight and frequency of the blows struck, though the ore is in a hard flint.

In some mines of this district the stope and "splitter" holes are chambered, using one and a half to five boxes of powder concentrated in the chambers and with a heavy burden on the holes.[34] It is more common practice, however, not to chamber but to load the holes about two-thirds full of the explosive.[35] In this method of breaking from the solid the breccia tends to break out in the form of large bowlders, and considerable secondary breaking by bulldozing and sledging is required. Further details of the blasting practice in this district are given in U. S. Bureau of Mines Information Circular 6056.

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34 - Netzeband, Wm. F., Information Circular 6113, cited, pp. 7-8; Method and Cost of Mining Zinc and Lead at Mine No. 2, Tri-State District, Picher, Okla. Information Circular 6121, Bureau of Mines, 1929, p. 7.

35 - Banks, L. J., Work cited.
Keener, O. W., Metnod and Cost of Mining at Barr Mine Tri-State Zinc and Lead District. Information Circular 6159, 1929, 10 pp.

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In Southeast Missouri the ore is a mineralized dolomitic limestone which is almost, if not quite, free from silica. This is usually drilled with light hammer drills operated as one-man machines.[36] At one mine these drills are equipped with pneumatic feed,[37] and 80 to 100 feet are commonly drilled per machine shift. The ore is only slightly fractured, the rock joints and slips do not as a rule occur at close intervals, and little trouble is given by caving and fitchering. In contrast to the practice in the Tri-State district, the stope holes are usually drilled vertically downward. In the middle horizon of the ore formation the ground tends to break large, and some secondary breaking is required.

At Ducktown, Tenn., the ore is quite hard, and somewhat heavier machines are used. Medium-weight drifters are employed for drilling the slabbing holes on the sublevels, and unmounted hammer drills are used for the benching. Most of the ore is produced from the benching operations in which all the holes are drilled vertically downward. The machines are all operated as one-man drills.

The ground breaks in large blocks and considerable "blocking" is required. At Ducktown the blocking is done in grizzly chambers located directly over the haulage drift without any storage capacity between the grizzlies and the cars.[38]

At Mascot, Tenn.,[39] the ore is pulled from the "mills" through chutes and must be broken fine enough in the stope to pass these chutes. Some large slabs of ore are inevitably mixed with and covered by finer ore and do not make their appearance till they reach the chute. This necessitates considerable blasting in the chutes. At this mine the stope contractor also loads the cars, so that secondary breaking in the chutes is kept at a minimum.

At some iron mines using sublevel stoping the ground can easily be drilled with jackhammers employing auger steel.

Based upon data obtained from 19 mines (Table 3) and covering operations during the past two years, breaking (drilling and blasting) in open-stopes requires an average of 0.253 man-hours per ton of ore, (31.6 tons per eight-hour shift), with a minimum labor cost of breaking at the mines studied of 0.122 man hours per ton (65.5 tons per eight-hour shift) and a maximum of 0.556 man hours per ton (14.4 tons per eight-hour shift). The labor employed in breaking at 15 of these mines averaged 28.6 per cent of the total labor employed in the mining operations. At the various mines studied this percentage varies from 23.8 to 33.9 per cent except for one mine which had a low percentage of 13.8. At six iron mines using sublevel stoping the average man hours per ton expended in breaking ore in stopes was 0.154 (52 tons per eight-hour shift).

Powder consumption at 17 open-stope mines studied ranged from 0.421 pounds of 40 per cent gelatin per ton of ore to 1.265 pounds of 33 per cent ammonia gelatin per ton of

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36 - Poston, Roy H , Work cited

37 - Jackson, C. F , Work cited

38 - McNaughton, C H , Work cited

39 - Coy, H A , and Noble, James A , Work cited

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ore, the average being 0.783 pounds of explosive per ton of ore mined. Powder consumption for stoping only at nine mines averages 0.512 pounds per ton of ore.

Steel consumption as given by several mines was very variable, ranging from a low of 0.008 pound per ton of ore produced to .200 pounds per ton, the average being 0.100 pounds per ton.

Breaking, an important problem in any mine, takes on an added importance in open-stope mines. This may be due in part to the fact that some operations and problems involved in other methods of mining are absent or of very minor importance in open-stope mines.

Drilling and blasting operations constitute one of the major problems in open-stope mines, and considerable study and experimentation are warranted for the purpose of obtaining the most economical results. The type and size of drills best suited to the local conditions; kind, shape, and size of steel; type and gauge changes of bits; steel tempering and treatment; type of drill round; depth, spacing, and burden of drill holes; kind, grade, and most suitable density of explosive; methods of loading and firing; and economical proportioning of primary and secondary breaking are all matters requiring careful study.

The breaking and the handling of broken ore are intimately related, and the one can not be properly considered except in its relation to the other. The ore must be broken to suit the method of loading whether it be by hand, by power shovel, or by scrapers; it must in many cases be broken to pass through loading chutes at the bottom of the stopes and must be of size which can be readily loaded into and handled by the mine cars and skips. The most economical and efficient operation will be secured where there is a proper balance between the breaking, handling, and transportation operations.

The combinations of conditions affecting the problem vary in different districts, are often different in mines of the same district, and may even differ considerably in parts of the same mine; therefore no set rules can be given for standard practice. The point here made, however, is that in the open-stope mines the proper coordination of the drilling, breaking, and handling operations, with development of each to its highest efficiency, offers the greatest possibilities for over-all savings in operating costs. These departments of underground operation are of course of major importance in connection with other mining methods, but with methods other than open-stope such problems as support of stope, capping, and surface; protection of workmen against falls; ventilation; "clean" mining and prevention of dilution of ore with waste rock; timbering, etc., often present problems of equal or greater importance.

Mines employing open-stope methods in the Eastern and Central States represent a wide range of conditions, necessitating a good many variations in drilling, blasting, and handling practices.

HANDLING AND LOADING

Horizontal Deposits.- Where the ore bodies are of the thin, flat, blanket type and the bottom contours are such that practical haulage grades are possible over the greater

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part of the deposit, handling of the ore consists of loading by hand, power shovel, or scraper directly into cars (or "cans" in the Tri-State district) and tramming to the shaft by hand, animals, or locomotive haulage.

Usually to obtain best results a different type of car is required for power-shovel or scraper loading than where hand-shoveling is employed. The type and size of equipment best suited to the job are dependent also upon the life of the mine, rate of output desired, and length of haul. In some large mines with working faces at considerable distances from the shaft, the haulage of ore approaches a problem in railroading. Here maximum economy and efficiency are often made possible by employing large cars and locomotives, heavy rail and well-laid track, installing block-signal systems, etc.[40]

In thicker, flat deposits, levels are driven from the shaft at various elevations as required, raises are put up to the top of the ore or from level to level, and the ore is blasted down into the raises, whence it is drawn into cars on the haulage level. In this manner a large percentage of the ore may be handled from stope face to cars by gravity, as in mining deposits lying at steep inclinations. In the wide, flat deposits, however, considerably more level development is required than in steeply dipping ore bodies, and even then a certain amount of ore which can not be handled by gravity must always be left in "hog-backs" near the bottom of the deposit and between the chutes.

In the Tri-State district, ore is usually loaded into cans by hand. Most of the operators in the district claim this to be the cheapest method of loading under their conditions.[41]

At the Barr mine[42] both hand loading and power shovels are employed. The hand-loaders average 24.9 tons per man-shift, and the men operating the power shovels average 49.0 tons per man-shift. Basing their choice upon the successful experience some years ago at a property now worked out, the operators of a newly opened mine are to install scrapers. At still another new mine power shovels are to be employed.

In Southeastern Missouri, power shovels are used extensively for loading where the ore is thick enough to provide tonnage commensurate with shovel-loading and car-handling capacity. At one property[43] in this district the hand-loaders average 19.2 tons per man-shift in stopes while power-shovel operators average 135 tons per man-shift.

Deposits Having Low or Moderate Dips.- In thin deposits of low dip, too steep to allow running cars from the haulageway to the stope face yet flatter than the angle of repose of the broken ore, intermediate handling of the ore between the stope face and the car is required. In thick deposits a considerable part of the ore may be handled by gravity.

40 - Jackson, C. F., Work cited.

41 - Netzeband, Wm. F., Information Circular 6113, cited.

42 - Keener, O. W., Work cited.

43 - Jackson, C. F., Work cited

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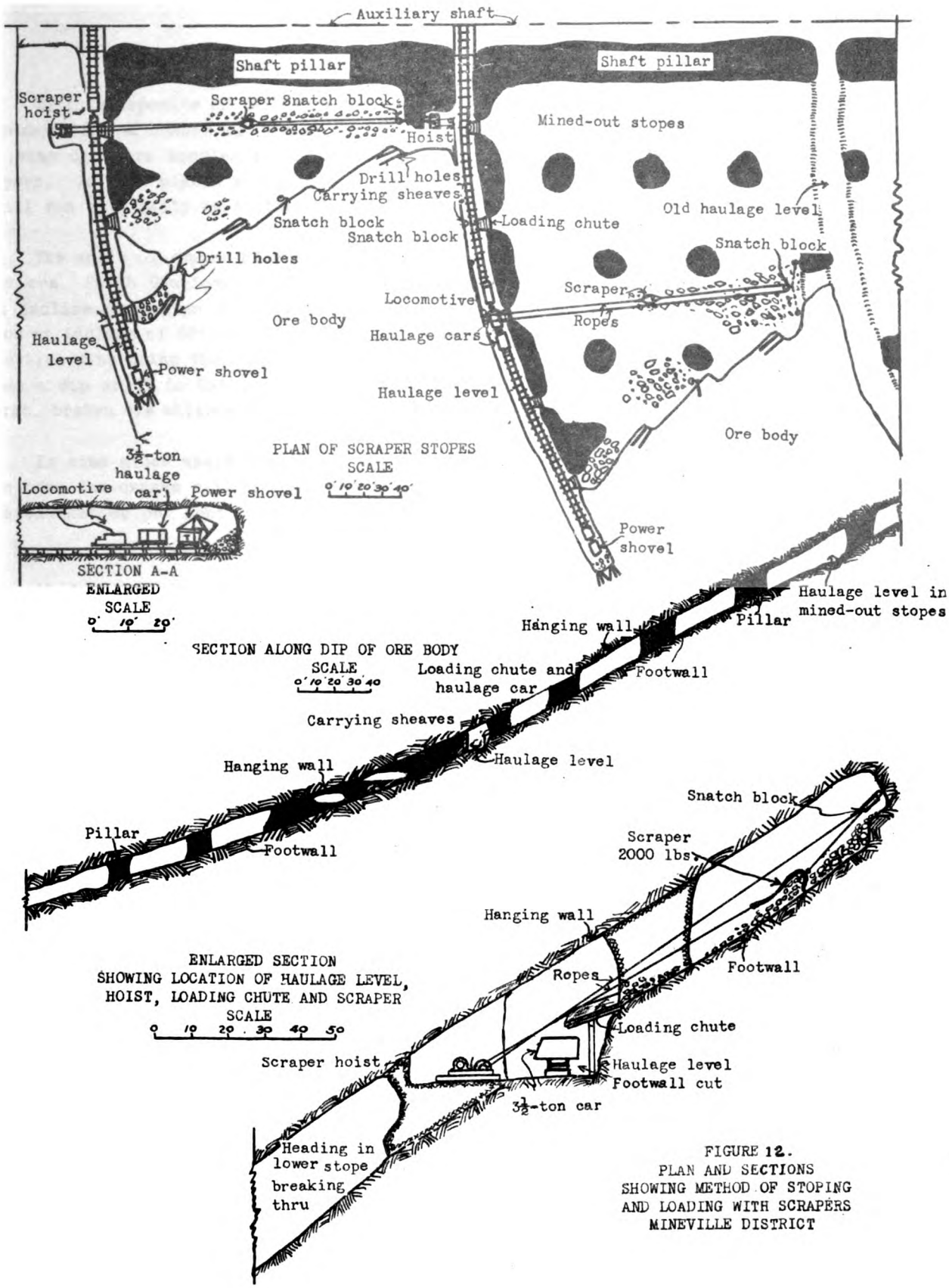

FIGURE 12.
PLAN AND SECTIONS
SHOWING METHOD OF STOPING
AND LOADING WITH SCRAPERS
MINEVILLE DISTRICT

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In thin deposits of this type the intermediate handling may be done by (1) shoveling and reshoveling a number of times, which is archaic; (2) driving inclined roadways upon which mine cars are handled by hoists; (3) the use of scrapers; or (4) shaking chutes or conveyors. In some places where the dip is only slightly less than the angle of repose the ore will run by gravity in a steel-lined chute.

The angle of repose of broken ore will vary considerably with the physical character of the ore In th Conglomerate Lode Keweenaw Peninsula, Mich., the broken ore will run on an incline as low as 35° and at 40° will run well. At the Noranda mine in Quebec it runs on an incline of 38°. Many broken ores, however, assume a much steeper angle of repose. At one iron mine using the sublevel stoping method, the ore runs to the chutes on a 45° dip, whereas a dip of 50 to 55° is required for many other iron ores. At the Paymaster mine in Ontario, broken ore which was a hard, schisted, albite porphyry often hung up on a 50° slope.

In some mines where the dip is approximately the same as the angle of repose of the broken ore, the chunks will run and the fines will hang up. In the Conglomerate Lode it is estimated that 60 per cent of the ore runs on a 35° dip and that 100 per cent will run on 40°.

At an iron mine in Michigan using a combination of open-stopes and pillars with shrinkage stoping, the lumps run to the chute by gravity while the fines have to be pulled down with scrapers. At this mine the ore varies from a few feet to 40 feet in thickness and dips at an average angle of 30 to 35°. Minor rolls in the footwall increase this dip or decrease it locally. In the thicker parts of the lens, broken ore is left in the stopes, shrinkage fashion, upon which the men work in attacking the back. In this case the broken ore does not serve to support the walls. When a stope is mined up to the next level above (about 150 feet along the dip) as much of this ore is drawn off by gravity through chutes as will run, and the balance is pulled down with scrapers.

At Mineville, N. Y.,[44] scrapers are commonly employed on the flat dips and in faulted sections for moving the ore from the stope faces to the tramming levels. Here the ore bodies have average dips of from 20 to 30°, and the ore is 3 to 40 feet thick and averages 10 feet of workable ore. The ore beds are displaced from a few feet to over 100 feet by a number of faults striking in various directions. In order to reach the ore in these faulted sections, a considerable number of auxiliary inclined shafts or slopes is required. Ore broken in stopes tributary to these inclines is in some cases loaded into cars at the face, trammed to the slope, and the cars then lowered or hoisted on the slope to the haulage level. More often, however, scrapers are employed to drag the broken ore from the face to small pockets or loading platforms from which cars, hoisted and lowered on the slopes, are loaded (fig. 12). In these mines the handling, haulage, and transportation costs account for about 56 per cent of the total underground cost, and therefore these operations constitute the major problem in connection with economical exploitation.

In the Birmingham district of Alabama, on dips ranging from 0 to 25°, large scrapers weighing from 2,700 to 3,100 pounds and operated by 50-hp. hoists are employed to drag the ore from the face of the stope for distances up to 200 feet into 5-ton cars on the haulage

44 - Cummings, A. M., Work cited

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level. Each scraper unit, consisting of a scraper outfit, hoist, and locomotive, loads and trams to the shaft an average of about 250 tons per 10-hour shift with three men. As much as 100 tons per hour for a duration of several hours has been handled in this manner under ideal conditions, and 300 tons per shift is a common performance. Some of the conditions making for successful scraper operation in this district are: (1) Keeping a large tonnage of broken ore ahead of the scraper at all times; (2) ore well broken for handling without excessive secondary breaking by blockholing or sledging; (3) large heavy scrapers of design suited to the material handled, operated by powerful hoists; (4) ample car supply and facilities for loading cars made up in trains without switching; and (5) large cars.

At Mascot, Tenn., the ore body dips at an average angle of 18°, and the workable ore ranges from 15 or 20 feet to 150 feet in thickness. The main level of the shaft intersects the top of the ore at some distance from the shaft, and in order to reach the lower horizons, slopes are driven at an angle approximately that of the dip of the ore. Cars are loaded from stope chutes on these lower levels and hoisted on the slopes to the shaft level, whence they are hauled to the shaft by locomotives. In sections where the ore is thin, the stopes are breasted out on the heading-and-bench plan, and the ore is shoveled by hand into mine cars. In thethick ore, present practice is to use an underhand milling method in the open-stopes.Irregular pillars are left to support the roof and whereer possiblo are confined to the lower-grade portions of the ore body. The mills are developed from raises opened from a haulage drift in the footwall. The bottoms of these raises terminate at the haulage level in chutes provided with gates for loading into the cars. The chutes are spaced at intervals along the haulage drift and the bottoms of the mills form a series of funnels with intersecting rims. Broken ore from the part of the stope above the tops of these funnels falls by gravity directly from the stope face to the chute. For recovering the hogbacks between the mills and the ore left below the angle of repose of broken ore, scrapers operated by 25-hp. electric hoists are employed to drag the ore into the chutes. Scraping ore to the chutes cost 8 cents per ton in 1923. The ground breaks large, and secondary blasting is employed in the stopes and in the chutes in order to reduce large bowlders to a size which will permit them to pass through the chutes and which can be handled in the mine cars and skips.

In the copper mines of Michigan, scrapers are used extensively to drag the ore from open-stopes in lodes of flat dip. These scrapers either pull the ore directly into cars or into chutes installed at the haulage level.[45] On steeper dips it is often the practice to allow the ore to run from the face down into the haulage level below and from there to pick it up by scrapers which drag it up an incline onto a loading platform from whence it falls into cars. Where this is done, about 100 tons is usually loaded per shift per scraper.

Deposits Having Steep Dip.- When the dip is greater than that of the angle of repose of the broken ore, intermediate handling between stope face and level is not required. The broken ore falls by gravity into mills or chutes, to grizzlies or into the level, from whence it is loaded into cars.

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45 - Crane, W. R., Work cited

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In most open-stopes the ore when broken from the face is in such condition that more or less secondary breaking is required. In flat deposits large chunks are usually rolled to one side during loading of the finer ore and are broken up at convenient times. In steep deposits, however, chunks and fines fall together, and the chunks usually have to be broken immediately upon their appearance at the loading chute in order that loading may continue.

Various methods are in use for secondary breaking. In some mines the practice is to break the chunks on top of the muck pile before it is drawn. In this event only part of the chunks are broken up before reaching the pull point, as the balance are covered by finer ore, so that further blasting must be done in the chute when the chunks appear there.

In other mines no attempt is made to break large chunks till they appear at the chute or loading point on the haulage level. Breaking in the chute has several disadvantages: There is always a certain amount of danger connected with blasting in chutes; loading is seriously delayed while preparing for blasting; frequently further delay occurs while awaiting for the smoke to clear after the blast, and sometimes levels are smoky during the entire shift when much chute blasting is done; blasting often damages the chutes, making repair costs unduely large; delays caused by blasting reduce the amount of ore per shift which can be drawn from each chute, and more stopes must then be provided to secure the same output.

In some open-stope mines grizzlies are installed above the haulage level which are connected to the stope by large openings, and all secondary breaking is done on these grizzlies (figs. 5 and 6). The installation of grizzlies requires some additional development cost and shortens the effective height of stopes between levels; on the other hand, they provide a convenient and safe place in which to work, away from the miners in the stope itself and from the tramming level. When properly installed they permit rapid loading into cars on the haulage level, particularly if some storage space is provided between the level and the grizzly. At the Paymaster mine in Ontario one locomotive engineer and two loaders regularly loaded 400 tons in two and a half to three hours. The grizzlies were 24 feet above the back of the haulage level, and wide, under-slung gates permitted rapid drawing of rather rough muck through the chutes.

At the Burra Burra mine[46] the grizzlies are placed directly over the haulage level (fig. 13), and the ore is broken through the grizzly directly into cars without intermediate storage. At this particular plant requirements as to ore analysis demanded that ore be drawn from a number of stopes, and it was not desirable to force production from any one stope. Earlier experience at this mine was that it required as much time to draw ore from the storage space as it did to block the ore through the grizzlies when the grizzlies were placed higher up. With the present system an average of 72.5 tons per man per shift is put through the grizzlies and loaded into cars.

Grizzlies are used at some of the Michigan iron mines employing the sublevel stoping method, and at others the ore runs directly to the mill holes Where the ore is hard and breaks in large slabs, the use of grizzlies is desirable. With the softer and more friable ores the installation of grizzlies is probably not justified. Furthermore, at some of the

46 - McNaughton. C. H., Work cited, pp. 7 and 8.

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mines the ground is so heavy that the maintenance of grizzly chambers would be difficult

At one of these mines employing sublevel stoping, four active stopes, having three grizzlies to each stope (fig. 6), provided an output of 700 tons per day and could easily produce 1,000 tons, or an average of 250 tons per stope. At another mine developed similarly, the output was 150 to 300 tons per stope per day, the average being 250 tons.

At other substope mines where the ore is softer, raises are usually spaced at 15 to 20 foot intervals along the haulage drifts on alternate sides of the drift (fig. 8), the haulage drifts themselves being driven on 40 to 50 foot centers. At one mine developed in this manner where the ore is somewhat harder but generally breaks with a very small proportion of large chunks, three sublevel stopes were producing 1,050 tons per day, working only one shift.

As stated (page 17), the breaking of the ore constitutes one of the major operations in open-stope mines; the average labor cost of breaking, including both development and stoping, at 15 of the mines studied was 0.283 man hours per ton of ore, and this was 28.6 per cent of the total man hours per ton worked underground.

For the same group of mines, the mucking labor cost averaged 0.263 man hours per ton (30.4 tons per mucker shift) and the transportation 0.275 man hours per ton (29.1 tons per transportation shift.) Transportation includes loading, tramming, motor haulage, and hoisting. Since the mucking and transportation operations overlap in most mines and as the line of demarcation between them varies at different mines these operations will be considered together. The combined mucking and transportation labor cost for these mines averaged 0.538 man hours per ton (14.9 tons per shift) and accounted for 54.8 per cent of the total underground man hours per ton. The range was from 0.415 man hours per ton (19.25 tons per shift) to 0.722 man hours per ton (11.08 tons per shift.) The first figure is that for a mine in which the handling, loading, and transportation are all largely mechanized, whereas the high figure is that for a mine in which all handling, loading, and transportation are done by hand.

Four mines in flat ore bodies mined by open-stopes with pillar support in which loading and handling were partly mechanized averaged 0.5445 man hours per ton, and five mines of the same type in which all loading was by hand, averaged 0.6188 man hours per ton for loading and transportation.

The foregoing figures include both stoping and development. They serve to indicate the importance of loading and underground transportation in mines of the type under disussion.

COSTS

In Table 2 and Table 3 the underground costs at a group of mines employing open-stope methods are given. Table 2 gives the costs in dollars and Table 3 in man hours per ton.

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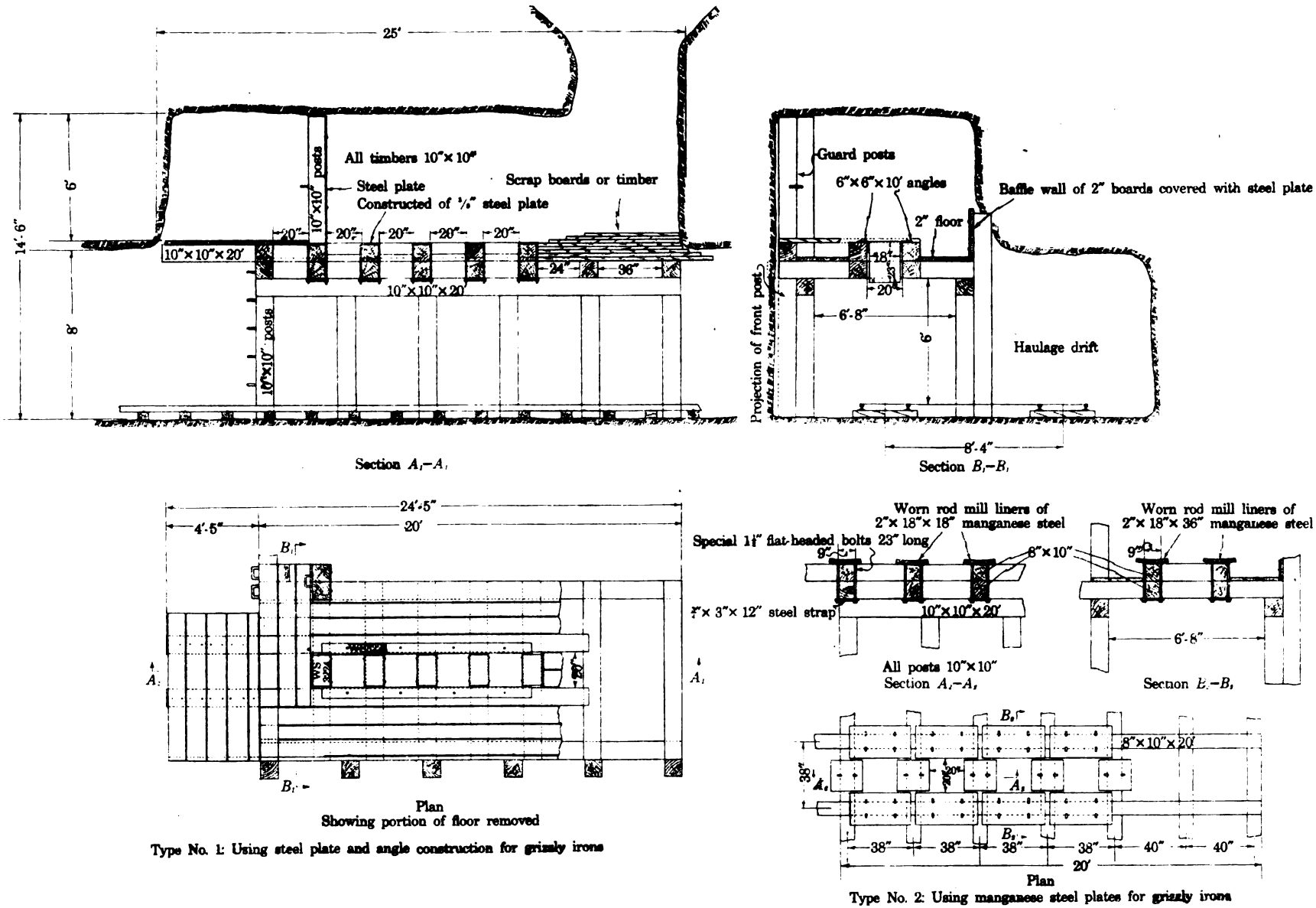

Figure 13 - Types of grizzlies used at Ducktown, Tenn.

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Costs in dollars are apt to be misleading for comparative purposes, inasmuch as wage rates, rail transportation, and cost of explosives, timber, and supplies vary considerably in different districts. For comparative purposes costs in units of labor and materials are generally more useful and may often serve as a valuable yardstick to the operator for measuring the efficiency of his own operations.

It is emphasized that comparisons between costs at the mines listed in the tables are apt to be misleading without full knowledge of the conditions at each mine, and hasty comparisons should be avoided.

Some of the mines were developing at a rate faster than that required to keep pace with ore extraction; one of the mines is approaching exhaustion, and the cleaning up of irregular tongues of ore greatly increases costs. There is also a wide variation between different mines in the amount of exploration and development required to locate and open up the ore for mining, due to size and type of ore deposits.

Most of these mines have been or will later be described in a series of papers published by the U. S. Bureau of Mines as Information Circulars, and from these circulars considerable detailed information concerning them may be gained.

The author has visited all of these mines, and in the preceding pages has included such comparisons and averages of the data as were deemed useful and safe. During the next six months it is anticipated that considerable additional data will be available and published by the Bureau of Mines in the form of Information Circulars dealing with individual operations.

Mining operations are conducted primarily for the purpose of producing profits, and it must be born in mind that the lowest mining cost per ton of ore does not necessarily mean the highest over-all profit for the enterprise. Percentage of recovery of tonnage and metallic contents of the ore, effects of dilution of the ore, rate of production, safety in working, and such factors must be considered. Examples are not uncommon of changes from lower to higher cost per ton methods in which the cost per pound of metallic product is lower for the high cost per ton of ore method than for the low cost method.

Table 2 and Table 2A show distributions of costs for a number of the mines studied, the average costs, and percentage of total underground costs which each of the principal divisions of underground work represents.

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Table 2.- Open-Stope Mines: Underground Costs

Designation	Stoping system	Development	Mining	Transportation	General	Total
1 Mineville	Open stopes with casual pillars	$0.092	$0.370	$0.627	$0.023	$1.112
2 Marquette No. 1	Regular stope and pillars breast and bench mining	.194	.685	.217	.160	1.256
3 Marquette No. 2	Sublevel stoping	.223	.371	.133	.231	.958
4 Menominee No. 1	Sublevel stoping	.188	.415	.154	.071	.828
5 Ducktown No. 1	Sublevel stoping	.229	.332	.386	.188	1.135
6 Ducktown No. 2	Regular stope and pillar underhand stoping	.355	.545	.714	.214	1.828
7 No. 8 S.E. Missouri	Open-stopes with casual pillars	.045	.483	.222	.136	.886
8 Mine X	Open-stopes with casual pillars	.137	.367	.145	.179	.827
9 Michigan Copper B	Large stopes with large pillars	.197	.498	.520	.008	1.223
10 Michigan Copper C	Long, narrow stopes with rib pillars	.379	.617	.479	.048	1.523
11 Tri-State No. 1	Open-stopes with casual pillars	.049	.532	.217	.187	.985

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Table 2.- Open-Stope Mines: Underground Costs - Continued

Designation	Stoping system	Development	Mining	Transportation	General	Total
12 Tri-State No. 2	Open-stopes with casual pillars	$0.050	$0.458	$0.200	$0.285	$0.993
13 Tri-State No. 3	Open-stopes with casual pillars or no pillars	.030	.450	.165	.162	.807
14 Waco Tri-State	Open stopes with casual pillars	.050	.490	.155	.090	.785
15 Barr Tri-State	Open-stopes with casual pillars	.047	.497	.217	.107	.862
Numerical average		0.151	0.474	0.303	0.139	1.067
Percentages of total cost		14.2	44.4	28.4	13.0	100.0

Note:- 1-2-3-4 are iron ore mines for which reported figures are based on the long ton of 2,240 pounds. In this table the reported figures have been reduced to short ton basis to conform with the costs at other mines.

11 - Distribution of all costs estimated by author.

12-13 - Distribution of costs as between development, mining, and transportation estimated by author.

14-15 - Distribution of costs as between mining and development estimated by the author.

1. Bedded deposit of hard magnetite ore. Information Circular 6092.
2. Hard specular hematite ore. Information Circular 6138.
3. Soft hematite ore with strong walls. Information Circular,6179.
4. Soft hematite ore with medium strong walls. Information Circular 6180,
5. Hard cupriferous pyrites and pyrhotite, strong walls, Information Circular 6149.
6. Hard cupriferous pyrites and pyrhotite, strong walls.
7. Disseminated lead ore in limestone beds. Information Circular 6160.
8. Bedded deposit in limestone.

9 and 10. Native copper in amygdaloidal beds; deep mines . Bulletin 306.

11-12-13-14-15. Zinc and lead ore in beds of brecciated flint and limestone. Information Circulars 6113, 6121, 6150, 6159.

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Table 2A.- Open Stope Mines: Underground Costs

	Designation	Labor and supervision	Compressed air, drills and steel	Power	Explosives	Other supplies	Total
1	Mineville	$0.672	$0.138	$0.077	$0.127	$0.098	$1.112
2	Marquette No. 1	.795	.136	.096	.121	.108	1.256
3	Marquette No. 2	.526	.069	.125	.061	.177	.958
4	Menominee No. 1	.500	.099	.062	.115	.052	.828
5	Ducktown No. 1	1.744	.083	.035	.126	.142	1.135
6	Ducktown No. 2	1.169	.231	.216	.142	.070	1.828
	No. 8 S.E. Missouri	.637	.081	.046	.072	——	.886
	Tri-State No. 1	.624	.127	.041	.110	.083	.985
	Tri-State No. 2	.576	.114	.076	.157	.070	.993
	Tri-State No. 3	.545	.076	.047	.117	.022	.807
	Waco Tri-State	.536	.068	.109	.072	——	.785
	Barr Tri-State	.529	.066	.048	.103	.116	.862
	Averages.....	0.658	0.108	0.082	0.110	0.018	1.036
	Per cent of total underground cost.....	63.5	10.4	7.9	10.6	7.6	100

1-2-3-4. Iron ore mines for which reported figures are based on the long ton of 2240 pounds. In this table the figures are reduced to short ton basis to conform with data from other mines.

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Table 3.- Open-Stope Mines: Stoping Costs in Man Hours Per Ton

Designation	Man hours per ton							Total tons per man-shift, all labor except development
	Breaking, stopes only	Timbering	Mucking	Handling haulage and hoisting.	General	Super-vision	Total man hours per ton	
1 Mineville	0.210	——	0.427	0.172	0.009	0.066	0.884	9.05
2 Marquette No. 1	.304	.045	.276	.196	.086	.033	.940	8.51
3 Marquette No. 2	.195	——	.159	.196	.102	.034	.686	11.66
4 Menominee No. 1	.353	.038	.011	.142	.056	.028	.628	12.74
5 Ducktown No. 1	.348	——	.258	.205	.089	.174	1.074	7.45
6 Ducktown No. 2	.556	——	.622	.576	.241	.105	2.100	3.81
7 No. 8, S.E. Missouri	.122	——	.319	.264	.121	.049	.975	9.14
8 Mine X	.197	——	.231	.184	.141	.032	.785	10.19
9 Michigan Copper B	.274	.002	——	.457	.093	.058	.884	9.05
10 Michigan Copper C	.341	.002	——	.284	.163	.047	.837	9.56
11 Tri-State No. 1	.377	——	.407	.282	.247	.028	1.341	5.97
12 Tri-State No. 2	.297	——	.345	.125	.078	.031	.876	8.93
13 Tri-State No. 3	.139	——	.262	.366	.069	.069	.905	9.13
14 Waco Tri-State	.280	——	.355	.367	.013	.026	1.041	7.68

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Table 3.- Open-Stope Mines: Stoping Costs in Man Hours Per Ton - Continued

Designation	Man hours per ton							Tota. tons per man-shift, all labor except development
	Breaking, stopes only	Timbering	Mucking	Handling haulage and hoisting.	General	Super-vision	Total man hours per ton	
15 Barr Tri-State	.223	——	.279	.305	.051	.030	.888	9.01
16 Iron Mine A	.178	——	——	——	——	——	——	——
17 Iron Mine B	.160	——	——	——	——	——	——	——
18 Iron Mine C	.125	——	——	——	——	——	——	——
19 Iron Mine D	.123	——	——	——	——	——	——	——
Average breaking 1 to 19	.253	——	——	——	——	——	——	——
Averages 1 to 15 inclusive	.231	.006	.263	.275	.104	.054	.983	8.79
Percentage of tota. labor, 1 to 15 inclusive	28.6	0.6	26.8	28.0	10.5	5.5	100.0	——

Note:- 1-2-3-4 are iron-ore mines for which reported figures are based upon the long ton of 2 240 pounds In this table the reported figures have been reduced to the short ton basis to conform with data from other mines

Table 4.- Open-Stope Mines; Explosives used per ton of Ore Broken in Development and Stoping Combined

Designation	Stoping system	Explosives		Pounds explosive per ton of ore broken		
		Kind	Strength	Devel. only	Stoping only	Total
1. Mineville	Open-stopes with casual pillars	Gelatin	¼ - 40% ½ - 25%	——	0.711	0 834
2. Marquette No. 1	Regular stope and pillars; breast and bench mining	Amm. L.F.	50% an. 60%		.627	.802
3. Marquette No. 2	Sublevel stoping	Amm. Gel.	60%	——	.217	421
4. Menominee No. 1	Sublevel stoping	——	40% - 50%- 60%	——	.551	.735

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Table 4.- Open-Stope Mines: Explosives Used Per Ton of Ore Broken in Development and Stoping Combined - Continued

Designation	Stoping system	Explosives		Pounds explosive per ton of ore broken		
		Kind	Strength	Deval. only	Stoping only	Total
5. Ducktown No. 1	Sublevel stoping	Ammon.	40%	2.240	———	.755
6. Ducktown No. 2	Regular stope and pillar, underhand stoping	Gel. D.	40%	4.806	.420	.782
7. No. 8, S.E. Missouri	Open-stopes with casual pillars	Bulky Amm. Gel.	¾ - 25% ½ - 35%	———	———	.634
8. Mine X	Open-stopes with casual pillars	Amm. Gel.	40%	———	———	.550
9. Michigan Copper B	Large open-stopes with large pillars	———	———	———	———	.991
10. Michigan Copper C	Long narrow open-stopes with rib pillars	———	———	———	———	.978
11. Tri-State No. 1	Open-stopes with casual pillars	Amm.	33%	———	———	.750
12. Tri-State No. 2	Open-stopes with casual pillars	Amm.	33%	———	———	1.265
13. Tri-State No. 3	Open-stopes with casual pillars or no pillars	Gel. D.	20%	———	———	.875
14. Waco Tri-State	Open-stopes with casual pillars	Bulky	25%	———	———	.594
15. Barr Tri-State	Open-stopes with casual pillars	Amm.	40%	———	———	.905
16. Iron Mine A	Sublevel stoping	Gel. D.	40%	———	.543	———
17. Iron Mine B	Sublevel stoping	Gel. D.	40%	———	.600	1.020
18. Iron Mine C	Sublevel stoping	Gel. D.	40%	———	———	.516
19. Iron Mine D	Sublevel stoping	Gel. D.	40%	———	.446	———
Averages, 5 and 6		———	———	3.523	———	———
Averages, 1-2-3-4-6-16-17-19		———	———	———	.512	———
Averages, 1 to 15 inc. 17-19		———	———	———	———	.783

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Table 5.- Power consumption in mines using open-stope methods

Designation	Stoping system	Kilowatt-hours per ton of ore hoisted							
		Comp. Air	Hoisting	Haulage and lighting	Pumping	Ventilation	Mech. loading	Misc.	Total
Mineville	Open stopes, casual pillars	5.16	4.64	0.85	0.26	----	---	---	10.91
Marquette No. 1	Regular stopes and pillars	4.33	2.04	0.76	4.02	----	0.41	---	11.56
No. 2	stoping	4.24	2.30	0.94	1.79	----	---	0.13	9.39
Menominee No. 1	Sub.evel stoping	5.90	3.54	0.47	1.89	----	---	---	11.80
Ducktown No. 1	Sublevel stoping								7.92
Ducktown No. 2	Regular stope and pillar, underhand	8.75	Steam 81.10 lbs. coal	1.75	---	----	---	---	10.50 81.1 lbs. coal
No. 8, S.E. Missouri	Open-stopes. casual pillars								4.56
Mine X	Open-stopes casual pillars	3.70	0.50	0.90	5.00	----	0.20	---	10.30
Tri-State No. 1	Open-stopes, casual pillars	6.00	2.77	0.92	0.22	----	---	---	9.91
Tri-State No. 2	Open-stopes, casual pillars	2.51	2.42	---	0.82	----	---	---	5.75
Tri-State No. 3	Open-stopes, casual pillars or no pillars	1.40	2.77						4.17
Waco, Tri-State	Open-stopes, casual pillars								6 65
Barr Tri-State	Open-stopes, casual pillars	2.16	2.79	1.14	---	----	---	---	6.09
Average all mines									8.40
Average 10 mines		4.415							
Average 2 mines							0.305		

Note: 1 -Practically all ore mechanically loaded

2 -Half the ore mechanically loaded

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8. Mine X	Open-stopes with casual pillars	Amm. Gel.	40%	———	———	.550
9. Michigan Copper B	Large open-stopes with large pillars	———	———	———	———	.991
10. Michigan Copper C	Long narrow open-stopes with rib pillars	———	———	———	———	.978
11. Tri-State No. 1	Open-stopes with casual pillars	Amm.	33%	———	———	.750
12. Tri-State No. 2	Open-stopes with casual pillars	Amm.	33%	———	———	1.265
13. Tri-State No. 3	Open-stopes with casual pillars or no pillars	Gel. D.	20%	———	———	.875
14. Waco Tri-State	Open-stopes with casual pillars	Bulky	25%	———	———	.594
15. Barr Tri-State	Open-stopes with casual pillars	Amm.	40%	———	———	.805
16. Iron Mine A	Sublevel stoping	Gel. D.	40%	———	.543	———
17. Iron Mine B	Sublevel stoping	Gel. D.	40%	———	.600	1.020
18. Iron Mine C	Sublevel stoping	Gel. D.	40%	———	———	.516
19. Iron Mine D	Sublevel stoping	Gel. D.	40%	———	.446	———
Averages, 5 and 6		———	———	3.523	———	———
Averages, 1-2-3-4-6-16-17-19		———	———	———	.512	———
Averages, 1 to 15 inc. 17-19		———	———	———	———	.783

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Table 5.- Power consumption in mines using open-stope methods

Designation	Stoping system	Kilowatt-hours per ton of ore hoisted							
		Comp. Air	Hoisting	Haulage and lighting	Pumping	Ventilation	Mech. loading	Misc.	Total
Mineville	Open stopes, casual pillars	5.16	4.64	0.85	0.26	----	---	---	10.91
Marquette No. 1	Regular stopes and pillars	4.33	2.04	0.76	4.02	----	0.41	---	11.56
No. 2	stoping	4.24	2.30	0.94	1.78	----	---	0.13	9.39
Menominee No. 1	Sub.evel stoping	5.90	3.54	0.47	1.89	----	---	---	11.80
Ducktown No. 1	Sublevel stoping								7.92
Ducktown No. 2	Regular stope and pillar, underhand	8.75	Steam 81.10 lbs. coal	1.75	---	----	---	---	10.50 81.1 lbs. coal
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Tri-State No. 1	Open-stopes, casual pillars	6.00	2.77	0.92	0.22	----	---	---	9.91
Tri-State No. 2	Open-stopes, casual pillars	2.51	2.42	---	0.82	----	---	---	5.75
Tri-State No. 3	Open-stopes, casual pillars or no pillars	1.40	2.77						4.17
Waco, Tri-State	Open-stopes, casual pillars								6.65
Barr Tri-State	Open-stopes, casual pillars	2.16	2.79	1.14	---	----	---	---	6.09
Average all mines									9.40
Average 10 mines		4.415							
Average 2 mines							0.305		

Note: 1 -Practically all ore mechanically loaded

2 -Half the ore mechanically loaded

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